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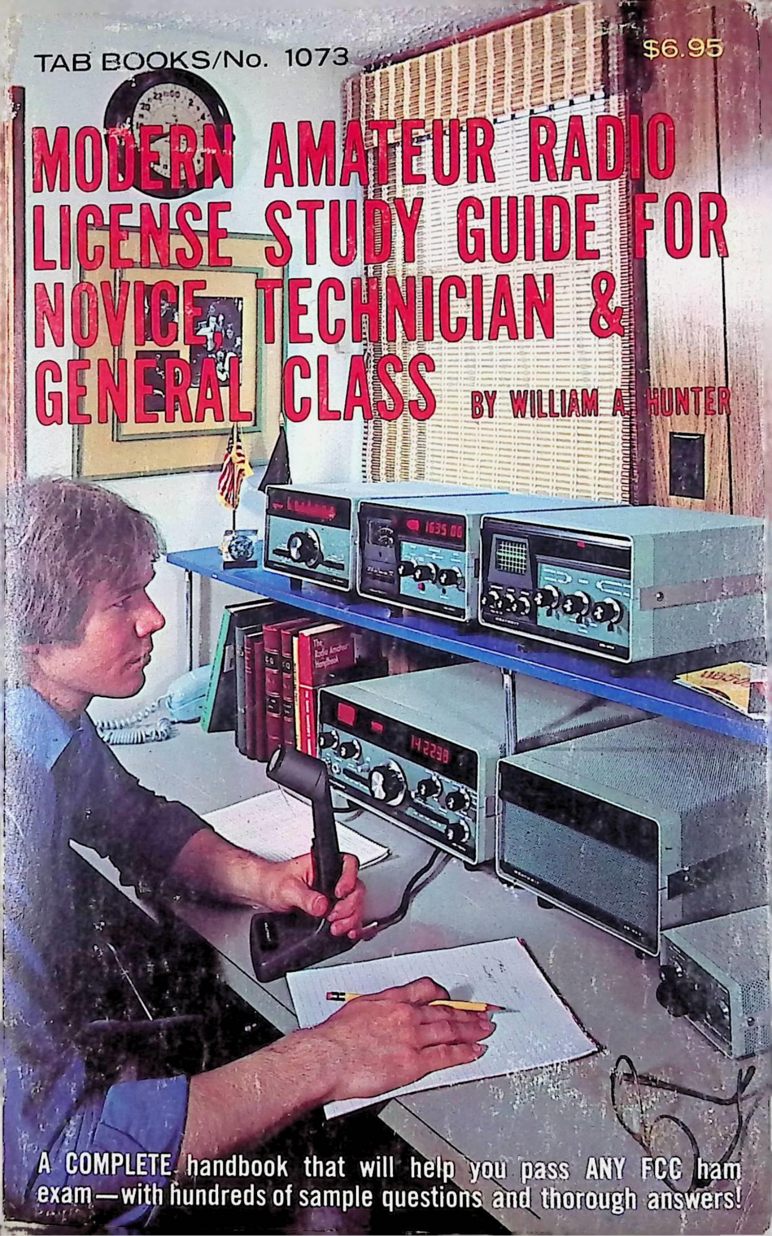
MODERN AMATEUR RADIO LICENSE STUDY GUIDE FOR NOVICE, TECHNICIAN & GENERAL CLASS

BY WILLIAM A. HUNTER



A COMPLETE handbook that will help you pass ANY FCC ham exam—with hundreds of sample questions and thorough answers!

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MODERN AMATEUR RADIO LICENSE STUDY GUIDE FOR NOVICE, TECHNICIAN & GENERAL CLASS

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To my daughters,

Diane and Lynda

MODERN AMATEUR RADIO LICENSE STUDY GUIDE FOR NOVICE, TECHNICIAN & GENERAL CLASS

BY WILLIAM HUNTER

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Foreword

For years the FCC issued a set of study questions for those interested in preparing for an amateur radio examination. And for years it was possible to buy books that had those same questions, along with short concise answers. If you had a good memory, you could simply memorize the answers and have a reasonably good chance of passing the written portion of the exam. The trouble was that little knowledge was gained from the exercise.

Within recent years the FCC has prepared *study guides* for the various classes of amateur radio licenses. The study guides have a few sample questions, but generally indicate subject areas you should know for the exam. Sets of questions are no longer issued. This approach more or less forces the applicant for a license to become more familiar with the subject matter itself. Strict memorization will no longer get you past the FCC examiners.

In preparing this book, I have used the study guides prepared by the FCC. Every topic mentioned in the FCC guide has been covered in this book—Part I for the Novice class examination, and Part II for the Technician and General class examinations. The book has been written in question and answer format, but you will find that the answers are not short and sweet. You will have a tough time just memorizing the answers. But that is what I intended. I want you to use this book not only to pass the written portion of the examination, but to learn about the fascinating hobby of amateur radio electronics. You will *know* something after you have studied this book.

This book is divided into two parts. Part I deals with those questions which may appear on the Novice class exam. It contains in-depth analysis of the workings of electronics—to a far greater extent than the simple questions on the FCC examination. After studying the book, you will have what you need to pass the test. And, you will have the ability to apply what you have learned to almost any situation you come across as a Novice.

Part II of this book looks at questions you are likely to find on the Technician and General class examinations (the written portion of the exam is the same for both classes). Again, as in the Novice section, I have covered every area suggested by the FCC study guide. In most cases I have more than merely answered the question—I have added other information that you are likely to need to know at some time during your *ham* career.

In both the Novice class and the Technician/General class examination given by the FCC, the questions and required answers are presented in an extremely simple format. You will not be required to write long involved essay-type answers. Study this book, and for either class, you will come through the exam with flying colors. As a fellow ham, I'll certainly welcome you into the group.

William Hunter, K6QAT

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Part I

The Novice Class

The simplest of all amateur radio license exams is the Novice class examination. The written portion of the exam consists of about 20 questions, and these deal with the very basics of amateur radio. The code test requires the sending and receiving of international Morse code at only 5 words per minute, or 25 characters per minute.

The Novice class was probably conceived to give those *interested* in amateur radio a chance to operate while they were learning radio theory and techniques, operating practices, rules and regulations, etc. The questions on the Novice exam are not meant for those who have had years of training or experience—they are designed for those with a minimum of knowledge about amateur radio. This enables those who are interested, but have little technical knowledge, to obtain an amateur radio license and enjoy the thrill of world-wide two-way radio communication.

A Novice license is good for only two years and cannot be renewed. During this period, those who hold a Novice license can operate their own amateur radio station while studying for a higher class exam. The experience gained in operating procedures can be of valuable assistance in the next exam. You'll find that your code speed seems to *automatically* increase as you use it more and more. And as you experiment with building your own transmitting and receiving systems, you can't help but acquire a certain amount of insight into those questions on that next FCC exam you'll take.

But first things first. Let's get past the Novice exam before we consider the Technician or General classes. Getting past the Novice exam is what the first part of this book is about. The study questions will prepare you for the Novice FCC exam. Our "set" of questions, however, is considerably longer and more detailed than those you'll encounter on the exam. We don't know for sure the *exact* questions you'll be asked, so we're going to prepare you for any that may appear on the exam.

The FCC exam covers nine areas. These areas are: (1) FCC rules and regulations, (2) radio phenomena, (3) operating procedures, (4) emission characteristics, (5) electrical principles, (6) practical circuits, (7) circuit components, (8) antennas and transmission lines, and (9) communication practices. All this, coupled with learning to send and receive Morse code, seems like a formidable task to a novice, doesn't it? But the answers involve a little technical knowledge and a lot of good old common sense, and learning the code at 5 words per minute is surprisingly easy for most of us.

Novice class examinations are administered by volunteer examiners selected by the applicant. The examiner, who conducts and supervises the examination, must be at least 21 years old, and must hold an Extra, Advanced, or General class amateur radio operator license. Almost any *ham* will help you with the exam.

The answers to the study questions here are not brief and abrupt answers, unless the nature of the question requires such an answer. You'll find that by studying the answers, you'll understand how to answer a similar question, and you'll know how to apply what you've learned. If you had simple questions and simple answers, you *might* be able to memorize them and you *might* be able to pass the FCC exam. But would you learn much? After you read and *study* the answers given in this study guide, you'll have a much better chance of passing the FCC exam on the first try.

Chapter 1

Basic Electrical Principles

To someone who has never been exposed to basic electronics, words such as *volts, ohms, amperes, inductance, capacitance*, etc. seem to represent a branch of physical science that is far too sophisticated for the average person. At first glance, some wonder if they should tackle the formidable task of learning about electronics. Just seeing or hearing these words is discourageing.

But once into it, we find the terms used in basic electronics are really not that difficult to comprehend after all. Suppose you want to water your lawn with the garden hose. When you turn on the water at the faucet, you find the nozzle at the end of the hose is closed, so no water escapes through it. You can see the hose expand slightly as the pressure builds up. We have a pressure in the hose measured in pounds per square inch. In electricity, the pressure of the movement of electrons (instead of water) is measured in volts.

If you open the nozzle a little, a small amount of water escapes. The nozzle provides a resistance to the flow of water. In electronics, devices called *resistors* provide a resistance to the flow of electrons. The amount of resistance is measured in ohms—a small number of ohms restricts the flow of electrons less than a large number of ohms. Twice as many electrons will flow through a 100-ohm resistor as through a 200-ohm resistor. We see that a resistor in a circuit provides a resistance to the flow of electrons, and the amount of the resistance is measured by the term *ohms*.

We've been speaking about the flow of the water, and the *flow* of the electrons. The movement, or flow, of electrons is called *current* in electronics. Current, too, has a term of measurement, known as the *ampere*.

As you might suspect, all three of these three basic terms are related, and that relationship is called *Ohm's law*. Ohm's law states that a current of one ampere will flow through a resistance of one ohm under a pressure of one volt. Stated another way, current varies directly with the voltage applied, and inversely with the resistance.

In this chapter you will learn many of the basic terms of electronics. You are sure to be asked about some of them on the FCC exam.

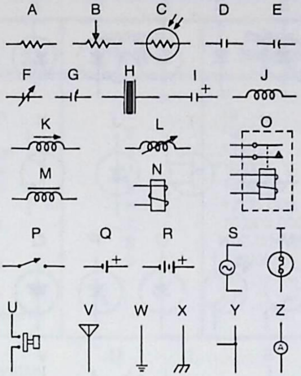
Before beginning the study, however, let's look at some of the common symbols used to identify circuit components. Figure 1-1 illustrates most of those used in amateur radio work, with the exception of semiconductor components. These solid state devices are shown in Fig. 1-2. You will be exposed to the symbols shown in the figures frequently in amateur radio, so it is a good idea to become familiar with each of them.

The last question of the section is a typical question prepared by the FCC for the Novice class exam.

1-1 What is the standard color code system for resistor values?

In the standard system, four bands are painted on the resistor as shown in Fig. 1-3. The color of the first band indicates the value of the first, most significant digit. The color of the second band indicates the value of the second significant digit. The third color band represents a decimal multiplier by which the first two digits must be multiplied to obtain the resistance of the resistor. The final band indicates the tolerance of the resistor. The colors used for the bands, and their corresponding values are shown in Table 1-1.

Using the example colors shown in Fig. 1-3A, since red is the color of the first band, the first significant digit is 2. The second band is blue, therefore the second significant figure is 6. The third band is orange which indicates that the number formed as a result of reading the first two bands is multiplied by 1000. In this case $26 \times 1000 = 26{,}000$ ohms. The last band indicates the tolerance.



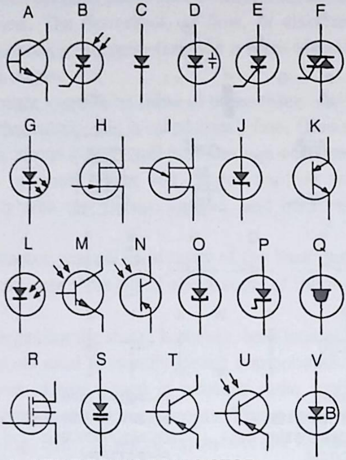
A—RESISTOR
B—POTENTIOMETER
C—PHOTORESISTIVE CELL
D—CAPACITOR
E—CAPACITOR
F—VARIABLE CAPACITOR
G—VARIABLE CAPACITOR
H—PIEZOELECTRIC CRYSTAL
I—ELECTROLYTIC CAPACITOR
J—INDUCTOR (COIL)
K—TUNABLE INDUCTOR
L—TUNABLE INDUCTOR
M—CHOKE
N—RELAY COIL
O—RELAY (SPST)
P—SINGLE-POLE SWITCH
Q—VOLTAIC CELL
R—BATTERY
S—AC SOURCE
T—FUSE
U—MOMENTARY CONTACT SWITCH
V—ANTENNA
W—EARTH GROUND
X—CHASSIS COMMON
Y—WIRE TIE POINT
Z—METER (LETTER IN CIRCLE TELLS FUNCTION: A-AMMETER, Ω-OHMMETER, V-VOLTMETER)

Fig. 1-1. Common circuit component symbols.

Its color is silver, and the tolerance is 10 percent. The allowed limit of variation in ohmic value will be from 23,400 to 28,600 ohms.

1-2 What do the letters V, I, R, E, h, f, W, and j represent in electronics work?

V—volts
I—current in amperes
R—resistance in ohms
E—electromotive force (EMF) in volts
h—inductance in henrys
f—capacitance in farads



A—NPN BIPOLAR TRANSISTOR
B—LIGHT-ACTIVATED SCR
C—DIODE
D—VARACTOR (TUNING DIODE)
E—THYRISTOR (SILICON CONTROLLED RECTIFIER)
F—TRIAC (BILATERAL SCR)
G—LIGHT-EMITTING DIODE
H—P-CHANNEL FET
I—UNIJUNCTION TRANSISTOR
J—ZENER DIODE
K—DIAC (BILATERAL TRIGGER)
L—PHOTODIODE
M—LIGHT-ACTIVATED NPN TRANSISTOR
N—PHOTODIODE
O—TUNNEL DIODE
P—PULSE SNAP DIODE
Q—TUNNEL DIODE
R—MOSFET
S—VARACTOR
T—PNP BIPOLAR TRANSISTOR
U—PHOTO TRANSISTOR
V—ZENER DIODE

Fig. 1-2. Solid-state component symbols.

Table 1-1. Resistor Color Code.

Color	Significant Figure	Decimal Multiplier	Resistance Tolerance
Black	0	1	Percent ±
Brown	1	10	---
Red	2	100	---
Orange	3	1,000	---
Yellow	4	10,000	---
Green	5	100,000	---
Blue	6	1,000,000	---
Violet	7	10,000,000	---
Gray	8	100,000,000	---
White	9	1,000,000,000	---
Gold	---	.1	5
Silver	---	.01	10
No Color	---	---	20

W—watts
j—joules

1-3 What is a volt?

The term *volt* (*V*) is the unit of electromotive force or electrical pressure. One volt is the pressure required to send one ampere of current through a resistance of one ohm.

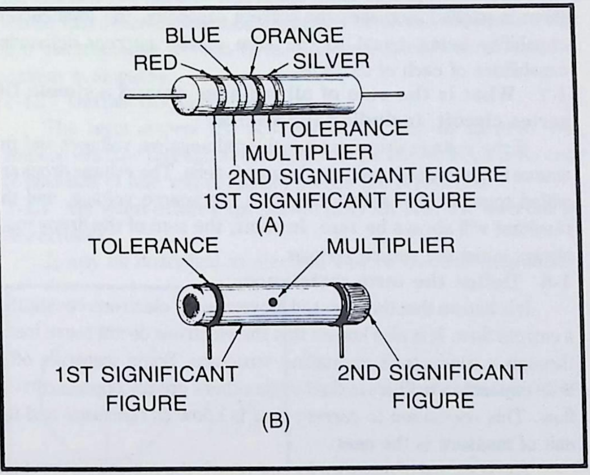


Fig. 1-3. Resistor color code.

1-4 By what other expression may "difference of potential" be described?

The most common expression is voltage, but the following terms are also used: *IR* drop, electromotive force (or EMF), intensity of charge, charge difference, charge pressure, electrical pressure, voltage drop, and fall of potential.

1-5 Define the term electromotive force.

In the everyday language of electronics the number of volts between two points is expressed in several different ways. Some of these are: voltage, potential, potential difference, and electromotive force (EMF).

Strictly speaking, each of these terms indicates a specific quantity, however, they are quite frequently used interchangeably. The term EMF for example, should only be used when referring to the force which causes charges to move through a source of voltage.

1-6 What method of connection should be used to obtain the maximum no-load output voltage from a group of similar cells in a storage battery?

Connecting cells in series increases the voltage according to the number of cells so connected, the total voltage being equal to the sum of the voltages of all the series-connected cells. Connecting them in parallel increases the current capability, the total current capability being equal to the sum of the current-delivering capabilities of each of the cells.

1-7 What is the sum of all voltages around a simple DC series circuit, including the source?

If the voltage drops are considered negative voltages and the source is considered positive, the sum is zero. The voltage drops are added together and subtracted from the source voltage, and the resultant will always be zero. In short, the sum of the drops must always equal the source voltage.

1-8 Define the term resistance.

It is known that the directed movement of electrons constitutes a current flow. It is also known that the electrons do not move freely through a conductor's crystalline structure. Some materials offer little opposition to current flow while others greatly oppose current flow. This opposition to current flow is know as *resistance* and the unit of measure is the *ohm*.

The standard of measure for one ohm is the resistance provided at zero degrees centigrade by a column of mercury having a cross-

sectional area of one square millimeter and a length of 106.3 centimeters. A conductor has one ohm of resistance when an applied potential of one volt produces a current of one ampere.

1-9 What is voltage drop?

As electrons flow through a resistor, they give up some of their energy in the form of heat. This heat is radiated into the surrounding air by the resistor. The farther through the resistor the electrons travel the more energy they lose. Upon reaching the end of the resistor, some of their original potential energy has been converted to heat energy. This loss of potential as the electrons travel through the resistor is called a *fall in potential* or a *voltage drop*.

1-10 What is an ohm?

The term *ohm* is the unit of measurement of resistance. One ohm of resistance will permit one ampere of current to flow when a potential difference of one volt is applied across the resistance. The symbol used to represent the ohm is the Greek letter omega (Ω).

1-11 State three mathematical forms of Ohm's law.

$$E = IR \qquad I = E/R \qquad R = E/I$$

If the formulas themselves are difficult for you to remember, try memorizing the diagram in Fig. 1-4. By covering the symbol for the function you need to figure, the other two symbols appear in a format that indicates whether to multiply or divide. Remember that E is electromotive force in volts, R is resistance in ohms, and I is current in amperes.

1-12 Define the term ampere.

The term *ampere* (A) is the practical unit of current. One ampere will flow through a resistance of one ohm when a difference of potential of one volt is applied across the resistance.

1-13 By what other expression may an electric current be described?

It may be described as electron flow or electron migration.

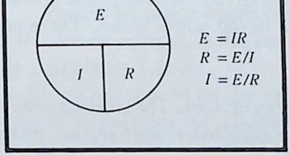


Fig. 1-4. An Ohm's Law memory aid.

1-14 What is the formula for determining the total resistance when all resistors in the circuit are in series? In parallel?

The formula for determining the total resistance of a circuit when all the resistors are in series is:

$$R_T = R1 + R2 + R3 + \ldots Rn.$$

The formula for determining the total resistance of a circuit when all resistors are in parallel is:

$$R_T = \cfrac{1}{\cfrac{1}{R1} + \cfrac{1}{R2} + \cfrac{1}{R3} + \cfrac{1}{R4} + \ldots \cfrac{1}{Rn}}$$

1-15 Define the term electrical power.

Power (P) is the rate of doing work per unit of time. Work results from a force acting on a mass over a distance. The operation of electrical circuits involves a force (voltage) acting on a mass (electrons) over a distance. The amount of time required to perform a given amount of work will determine the power expended.

Expressed as an equation, the relationship between power, work, and time is:

$$P = \frac{W}{t}$$

where: P = electrical power in watts
W = work in joules
t = time in seconds

Since energy is the capacity to do work, power can also be defined as the time rate of developing or expending energy.

1-16 What is a watt?

The watt (W) is the practical unit of electric power. It is the power required to do work at the rate of one joule per second. In a direct current circuit, the power in watts is equal to volts multiplied by amperes. In an alternating current circuit, the true power in watts is effective volts multiplied by the circuit power factor. There are 746W in one horsepower.

1-17 Define the term joule.

The joule (j) is the unit of energy or work. The absolute joule is equal to 10 million ergs. One joule is equal to one watt-second. In the

field of physical science, work is the product of displacement and force. The amount of work accomplished by movement of an object can be calculated by the equation:

$$W = Fd$$

Where: W = work performed

F = force applied in direction of displacement

d = distance through which the force acts

Since the metric units for force and displacement (distance) are the newton and the meter respectively, work is measured in newton-meters. One newton-meter has been named the joule. One joule of work is done when a force of one newton acts through a distance of one meter.

1-18 What is the formula for figuring the power in a DC circuit when the voltage and resistance are known?

The power is equal to voltage squared, divided by resistance, or:

$$P = E^2/R$$

1-9 What is the formula for determining power in a DC circuit when current and resistance are known?

The power is equal to current squared times resistance, or:

$$P = I^2R$$

1-20 What is the formula for determining power in a DC circuit when voltage and current are known?

Power is voltage multiplied by current, or:

$$P = EI$$

1-21 If two 10W, 500Ω resistors are connected in parallel, what is the dissipation capability of the combination?

The resistance value has no bearing on the power dissipation rating. If each resistor can dissipate 10W, the total power dissipation capability of the pair is 20W.

1-22 What will be the heat dissipation (in watts) of a 20Ω resistor having a current of 0.25A?

Power dissipation equals current squared times resistance, or I^2R. Current squared, in this case, is 0.0625A; this figure multiplied by 20Ω equals 1.25W.

1-23 What would be the minimum power dissipation rating of a resistor of 20,000Ω connected across a 500V source?

From Ohm's law we know that a 20K resistor connected across a 500V source draws 0.025A, or 25 mA. Power is equal to volts times amperes (EI), so we know the resistor will be required to dissipate 12.5W. Most resistors are rated at values of ⅛, ¼, ½, 2, 5, 10, 15, and 20 watts. The nearest standard value above 12.5W is 15W, which *is* the minimum value usable in the circuit.

To allow for possible changes in resistance and voltage, it is usually wiser to use a resistor that has a wider safety margin. So, while 15W would be the minimum acceptable rating, the 20W resistor would be the best choice.

1-24 What is the maximum current-carrying capacity of a resistor marked "5K, 200W"?

The maximum current allowable would be 282 mA (0.00282A) at full rated power. Current is equal to the square root of power divided by resistance ($I = \sqrt{P/R}$).

1-25 If the value of resistance to which a constant emf is applied is halved, what will be the resultant proportional power dissipation?

With applied voltage held constant, power is inversely proportioned to resistance ($P = E^2/R$). When resistance decreases, power dissipation increases proportionally; when resistance increases, power dissipation decreases proportionally. If resistance is halved, power dissipation is doubled.

1-26 Define the term conductance.

Conductance is the *reciprocal* of resistance and is used to express the ability of a material to support electron flow (current).

1-27 What is the unit of conductance?

This should be easy to remember if you can bear in mind that conductance is the reciprocal of resistance (conductance = 1/resistance). The basic unit is the siemens. (Until recently it was the *mho*, which was ohm spelled backward.)

1-28 What single-purpose instrument may be used to measure electrical resistance? Electrical current? Electromotive force?

The word single-purpose is used to prevent you from taking the easy way out and saying something like volt-ohm-milliam-meter (VOM). But the VOM (most of which don't measure power anyway) could hardly be considered a single-purpose instrument. Here's what you'd better be prepared to answer on the exam:

An *ohmmeter* measures *resistance*.

A *wattmeter* measures *electrical power*.

An *ammeter* measures *current*.

A *voltmeter* measures *electromotive force*.

1-29 What is the difference between direct current and alternating current? Define each term.

Electron current is defined as the *directed* flow of electrons. The direction of electron movement is from a region of negative potential to a region of less negative potential or more positive potential. Therefore, electric current can be said to flow from a negative potential to a positive potential. The direction is dermioned by the polarity of the voltage source.

Electric current is generally classified into two general types—direct current (DC) and alternating current (AC). A direct current flows continuously in the same direction, whereas an alternating current periodically reverses direction.

1-30 What is impedance and what is its unit of measurement?

Impedance (Z) is the AC equivalent of DC resistance, and the *ohm* is the unit of measurement. Impedance is the total opposition offered to the flow of an alternating current. It may consist of any combination of *resistance, inductive reactance,* and *capacitive reactance*.

1-31 State Ohm's law for AC circuits.

It may be stated in the same three basic forms as Ohm's law for DC circuits, except that impedance (Z) must be substituted for resistance:

$$E = IZ$$

$$I = \frac{E}{Z}$$

$$Z = \frac{E}{I}$$

1-32 Define the term rectification.

The transmission of electrical energy over great distances was made economical through the use of alternating current. Alternating current could be transmitted over great distances with a minimum of power dissipation within the transmission line.

Most electron tubes and many other electrical devices require a steady source of DC voltage. This voltage may be provided by a DC generator or by changing AC to DC. The process of changing AC to DC is called *rectification*. The devices used to accomplish rectification are called *rectifiers*.

1-33 Define the terms kilohertz and megahertz.

One of the more important measurements associated with light energy is that of *wavelength* measurement. Light may be analyzed by assuming it consists of waves similar to the ripples which are generated when a ball is dropped into a pool of water. The waves which are generated consist of a number of *cycles* such as from the crest of one wave to the crest of the next. In traveling from one crest to the next, the wave has gone through all of its possible variations. The number of these complete cycles per second is called the *frequency* of the wave. If the wave completes one cycle in 1/20 of a second, it would have a frequency of 20 cycles per second.

Frequency is measured in cycles per second, and expressed in *Hertz*. A prefix is attached to the word as a matter of convenience to express the frequency. One million cycles per second is said to be a frequency of one megahertz (MHz), while one thousand cycles per second is a frequency of one kilohertz (kHz). In radio waves, these two terms are the common terms used to express frequency.

1-34 Define the term capacitance.

Two conductors separated by a nonconductor exhibit the property called *capacitance*, because this combination can store an electric charge. Whereas inductance is a property of a circuit which opposes a change in *current*, capacitance is a property of a circuit which opposes a change in *voltage*. Where inductance stores energy in an *electro-magnetic* field, capacitance stores energy in an *electrostatic* field.

1-35 Define the term farad.

The farad is the unit of *capacitance*. A capacitor has a capacitance of one farad when a voltage change of one volt per second across it produces a current of one ampere. The farad is the basic unit of capacitance but is too large in amateur radio work. In radio, smaller units are used, such as the microfarad (μF), which is one-millionth of a farad, and the picofarad (pF), which is one-millionth of one-millionth of a farad.

1-36 What is the formula for determining the total capacitance when all capacitors in the circuit are in parallel?

The formula for determining the total capacitance of a circuit when all the capacitors are in parallel is:

$$C_T = C1 + C2 + C3 + \ldots Cn$$

1-37 What is the formula used to determine total capacitance of 3 or more capacitors connected in series?

Interestingly, the value of capacitors in *series* can be calculated exactly the way resistances in *parallel* are calculated: The value is equal to the reciprocal of the sum of the individual-value reciprocals, or

$$\frac{1}{C_T = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} + \frac{1}{C4}}$$

1-38 Define the term coulomb.

The coulomb is the basic unit of charge. Charged bodies act on each other with a force of attraction when they are oppositely charged and with a force of repulsion when they are similarly charged. The forces of attraction or repulsion change with the magnitude of the charges and the distance between them. Expressed mathematically, the relationship, known as Coulomb's law, is

$$F = \frac{Q_1Q_2}{d_2}$$

where Q_1 and Q_2 represent the charges and d is the distance between them. One coulomb is equal to the charge of 6.28×10^{18} electrons. It is also the amount of electricity that is transferred by a current of one ampere in one second.

1-39 Define the term inductance.

Inductance is the characteristic of an electrical circuit that makes itself evident by opposing the starting, stopping, or changing of *current flow*. In other words, inductance is the characteristic of an electrical conductor which opposes any kind of *changes* in current flow. (This differs from *capacitance*, which opposes any change in *voltage*.)

1-40 What is the definition of a henry?

The henry is the unit of *inductance*. The inductance of a circuit is one henry when a current variation of one ampere per second induces one volt. The henry is the basic unit of inductance, but is too

large in amateur radio work. In radio, smaller units are used, such as the millihenry (mH), which is one-thousandth of a henry, and the microhenry (μH), which is one-millionth of a henry.

1-41 What is the relationship between the number of turns and the inductance of a coil?

The inductance varies with the number of turns. The relationship is expressed in the equation

$$L = \frac{n\phi}{I}$$

where n is the number of turns, and ϕ is the magnetic flux linking the coil and produced by current I. Multiplying the result by 10^{-10} (0.0000000001) yields inductance in henrys.

1-42 State the formula for determining resonant frequency when inductance and capacitance are known.

Assuming a coil with a normal figure of merit (Q), the formula is

$$f = \frac{1}{2\pi\sqrt{LC}}$$

1-43 Explain how inductance produces transformer action.

When a conductor is placed within a magnetic field of a circuit in which the expanding or collapsing lines of force cut the conductor, a voltage will be induced in it. In this connection, consider coils 1 and 2 of Fig. 1-5 placed side by side.

Assume that battery B is connected to coil 1 and galvanometer G (an instrument for indicating the amount and direction of current flow) is connected to coil 2.

However, if you change variable resistance R, there will be a change in the current in coil 1. As a result, the flux through coil 2 will change, and the galvanometer will show a momentary deflection. The action in which a change in current in one coil induces a voltage in another coil is called mutual induction.

If, in a short period of time, the current in coil 1 in Fig. 1-5 changes and causes a change in the flux linking coil 2, the voltage induced in coil 2 is an emf of mutual induction. Its average value may be obtained mathematically.

Even though coils 1 and 2 are close together, not all of the flux produced by coil 1 links coil 2. The proportion that does link coil 2 is

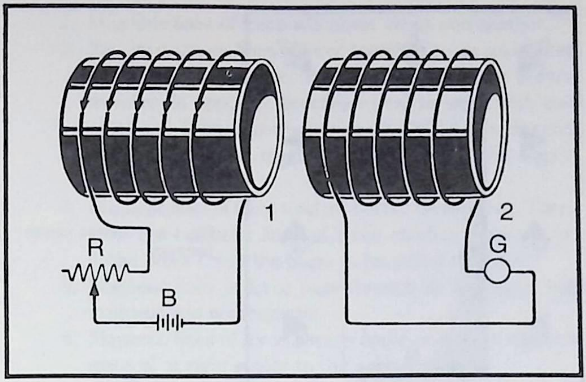


Fig. 1-5. Graphics for Question 1-43.

indicated by the symbol k, called the coefficient of coupling, which is always less than unity.

The flux in coil 1 may be assumed to be proportional to the current in that coil. The change in flux, then, is proportional to the change in current. The inductance of a coil of many turns is much greater than the inductance of a coil of a single turn, since the induced voltage is dependent not only on the change in flux but on the number of turns through which the flux passes. Inserting an iron core in a coil greatly increases the inductance;however,the increase is not constant over a wide range of current.

When two coils are placed close together, the relation between the mutual inductance (M) of two coils and their individual inductances (L1 and L2) is

$$M = k\sqrt{L1\ L2}$$

The transfer of energy from one circuit to another through mutual induction is referred to as transformer action.

1-44 What are magnetic fields?

The space surrounding a magnet where magnetic forces act is known as the magnetic field. One method used to obtain knowledge pertaining to a magnetic field is to explore the field with a compass.

By use of a compass, the characteristics of the magnetic field at various points near a magnet may be observed. Figure 1-6 shows the behavior of a compass needle as the compass is used to explore the

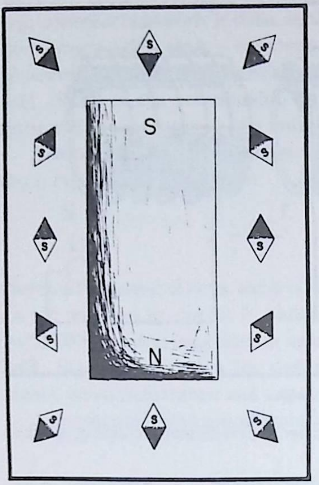


Fig. 1-6. Compass needle behavior.

field about a simple bar magnet. The compass needle aligns itself in various positions as it is placed at different points in the magnetic field. The alignment of the compass needle indicates a definite line of direction to the magnetic field.

1-45 What are magnetic lines of force?

To further describe and work with magnetic phenomena, lines are used to represent the force existing in the area surrounding a magnet (Fig. 1-7). These lines, called *magnetic lines of force*, do not actually exist but are imaginary lines used to illustrate and describe the pattern of the magnetic field. The magnetic lines of force are assumed to emanate from the north pole of a magnet, pass through the surrounding space, and enter the south pole. The lines of force then travel inside the magnet from the south pole to the north pole thus completing a closed loop.

1-46 What are the characteristics of magnetic lines of force?

The characteristics of magnetic lines of force can be described as follows:

1. Magnetic lines of force are continuous and will always form closed loops.

2. Magnetic lines of force will never cross one another.
3. Parallel magnetic lines of force traveling in the same direction repel one another. Parallel magnetic lines of force traveling in opposite directions tend to unite with each other and form into single lines traveling in a direction determined by the magnetic poles creating the lines of force.
4. Magnetic lines of force tend to shorten themselves. Therefore, the magnetic lines of force existing between two unlike poles cause the poles to be pulled together.
5. Magnetic lines of force pass through all materials, both magnetic and nonmagnetic.
6. Magnetic lines of force always enter or leave a magnetic material at right angles to the surface.

1-47 How is the oersted related to magnetic field intensity?

The intensity of a magnetic field is directly related to the magnetic force exerted by the field. The unit used in measuring field

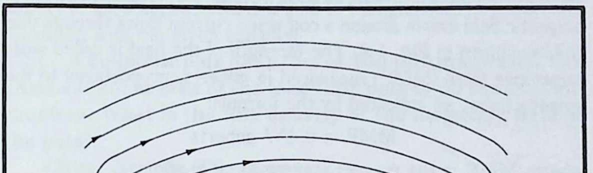


Fig. 1-7. Magnetic force lines.

intensity is the *oersted*, one oersted being equal to the strength necessary to exert a force of one dyne per unit pole. This relationship may be expressed mathematically as:

$$H = \frac{f}{m}$$

where: H = field intensity in oersteds
f = force acting upon a magnetic pole in dynes
m = strength of magnetic pole in unit poles

1-48 Define the term gilbert.

The gilbert is the unit of *magnetomotive force.* The value of the magnetomotive force in gilberts in any magnetic circuit is equal to the line integral around the circuit of the magnetic intensity when the magnetic intensity is expressed in oersteds, with length being in centimeters. One gilbert is equivalent to 0.7956 ampere-turns.

1-49 How is the magnetomotive force (MMF) measured?

The region around a bar magnet wherein its influence can be felt is called a magnetic field. This magnetic field can be thought of as a pattern of lines arranged in an orderly fashion leaving the north pole and entering the south pole, as shown in Fig. 1-7. A similar pattern of magnetic field exists around a coil when current flows through that coil, as shown in Fig. 1-8. The strength of the field is called *magnetomotive force* (MMF) measured in gilberts, proportional to the ampere turns, as indicated by the formula:

$$\text{MMF} = 0.4NI \text{ gilberts}$$

where: MMF = the magnetomotive force in gilberts.
0.4 = a conversion factor (sometimes given as 1.257).
N = the number of turns in the coil
I = the current flowing through the coil

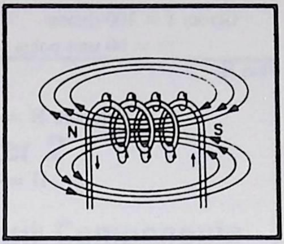
1-50 Explain the tems "magnetic flux", "flux density", "gauss", and "maxwell".

The total number of magnetic lines of force leaving or entering the pole of a magnet is called magnetic flux. The number of flux lines per unit area is known as flux density. This relationship can be expressed as an equation:

$$\text{B} = \frac{\phi}{\text{A}}$$

where the Greek letter beta (B) represents flux density, the Greek letter phi (ϕ) represents total magnetic lines of flux, and A is the

Fig. 1-8. Magnetic force pattern of a coil.



cross-sectional area. Most units of measure in magnetic studies are named in honor of scientists who worked with magnetics. The unit of flux density (B) is the gauss, and the unit of magnetic flux is the maxwell (equal to one line of magnetic flux). Area is measured in square centimeters.

The above mathematical equation shows the proportional relationship between the different units and can be accurately used only with a uniform magnetic field (that is, a field where each square centimeter contains exactly the same number of lines). The flux density of the magnetic field at a pole of a magnet can be accurately calculated with the given equation.

1-51 A magnetic pole has a flux of 300,000 maxwells. The cross-sectional area of the magnetic pole is 50 square centimeters. What is the flux density of the magnetic field at the pole?

Given: $\phi = 300{,}000$ maxwells
$A = 50$ square centimeters

Find B:

Solution: $B = \dfrac{\phi}{A}$

$$B = \frac{300{,}000}{50}$$

$$B = 6000 \text{ gauss}$$

1-52 What is the intensity of a magnetic field that exerts a force of 100 dynes on a magnet having a strength of 50 unit poles?

Given: $f = 100$ dynes

$m = 50$ unit poles

Find H:

$$\text{Solution: } H = \frac{f}{m}$$

$$H = \frac{100}{50}$$

$$H = 2 \text{ oersteds}$$

1-53 Define the term characteristic impedance.

Characteristic impedance, or *surge impedance*, has two generally accepted definitions. The most common definition states that characteristic impedance is the ratio of voltage to current at every point along a transmission line on which there are no standing waves. The second definition states that it is the square root of the product of the open and short-circuit impedance of the line.

In circuits that contain inductors and capacitors, the inductance and capacitance are present in definite "lumps." In an rf transmission line, however, these quantities are distributed throughout the entire line and cannot be separated from each other.

The characteristic impedance (or surge impedance) of a transmission line having infinite length is the impedance in ohms at the operating frequency, presented by the line to the source feeding the line. This impedance across the input of a theoretically infinite line has a very valuable use. If a load equal to this impedance is connected to the output end of the line, regardless of the length of the line, the impedance presented to the source by the input terminals of the line is still equal to the characteristic impedance of the transmission line. Only one value of impedance for any particular type and size of line acts in this way.

1-54 The electromotive force (EMF) that will produce a current of one ampere through a resistance of one ohm is a

A. Henry
B. Farad
C. Joule
D. Volt
E. Watt

Answer: *D*

Chapter 2

Functions of Circuit Components

By now you are somewhat familiar with the various components that are used in amateur radio. In this chapter we are going to learn the function of some of the more important components used in radio circuits. So far what we've learned has been fairly simple, with the exception of a hurdle or two. This chapter is a little bit more complicated, but don't let that scare you. It's really not that bad.

Some of the topics we'll cover are quartz crystals, chokes, power supply filters and regulation, bleeder resistors, diodes, and some troubleshooting hints. The *appearance* of a component helps us locate trouble, such as a blue haze in an electron tube or a red-hot plate in an electron rectifier tube. We discuss these in this chapter.

Obviously, in our limited amount of space, we cannot teach you all there is to know about every possible component you may ever encounter. But there is enough here to get you past the Novice FCC exam in flying colors. Study each answer given so that you will not only pass the test, but you will have some understanding about amateur radio electronics.

Now, let's get on with the questions.

2-1 What is the function of a quartz crystal in a radio transmitter?

When placed in an electrical circuit, a crystal acts like a very high-Q series resonant circuit. The electrical circuits associated with a crystal can be represented by an equivalent circuit (Fig. 2-1)

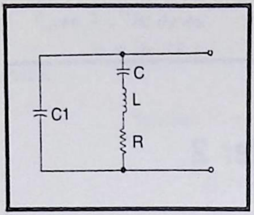


Fig. 2-1. Quartz crystal equivalent circuit.

composed of a resistance, inductance, and capacitance between the metal plates (C1) of the crystal holder. When the crystal is not vibrating, the circuit acts only as this capacitance. The series combination of L, C, and R represents the electrical equivalent of the vibrating crystal's characteristics. Since a quartz crystal is equivalent to a resonant circuit, it can be used in place of the usual tuned circuit in the oscillator section of a transmitter. The high Q of the crystal provides a stability that cannot be matched with ordinary LC components.

2-2 What is the purpose of an rf choke?

An rf choke is placed in a circuit to prevent the passage of radio-frequency energy. The choke offers a high impedance to rf but passes DC.

2-3 What is the principal function of a filter in a power supply?

The principal function of a filter in a power supply is to produce a DC voltage that is sufficiently smooth to avoid undesirable coupling of any AC components into an electronic circuit. If the pulsating DC voltage that is present at the output of a rectifier system were directly applied to a vacuum tube, the pulsations would cause improper operation of the tube.

2-4 What is the effect on a filter choke of a large value of DC flow?

During the period when the rectifiers are conducting, the choke opposes the current buildup; when the rectifiers are not conducting (as the input voltage returns toward zero), the stored energy in the choke supplies current to the load. As long as the current exceeds a minimum value (depending on the inductance of the choke), the regulation of the output voltage remains fairly high. With low-current loads, an ordinary filter choke functions in much the same manner as an electrolytic filter capacitor.

2-5 What are the characteristics of a capacitor input filter in a power supply as opposed to a choke input filter?

The capacitor input filter is capable of supplying a higher DC voltage (with a given input potential) under fairly light loads. Since the input capacitor can charge to almost peak input voltage, a properly designed capacitive input filter will provide a high output voltage in comparison to a choke input filter.

Capacitor input filters are typically used in applications where current drain is to be relatively small. As shown in Fig. 2-2, when a pair of vacuum-tube rectifiers is used in full-wave rectification, output voltage E remains at an almost constant average level when the load resistance (R_L) is not too low. Plate current (I_b) of the rectifiers increases as R_L decreases; the peak plate current drawn must be lower than the peak-current rating of the rectifiers.

The capacitor input filter is also characterized by poor regulation. The full-load voltage, when the load resistance is very low, drops significantly (Fig. 2-3). In comparison with the choke input filter, the capacitor input type will exhibit a greater change in output voltage from no-load to full-load condition.

2-6 What are the characteristics of a choke input system as compared with a capacitor input filter in a power supply?

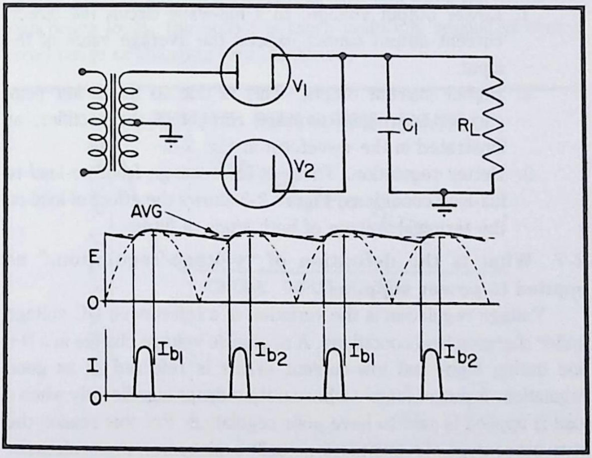


Fig. 2-2. Capacitor input filter's effect on output voltage.

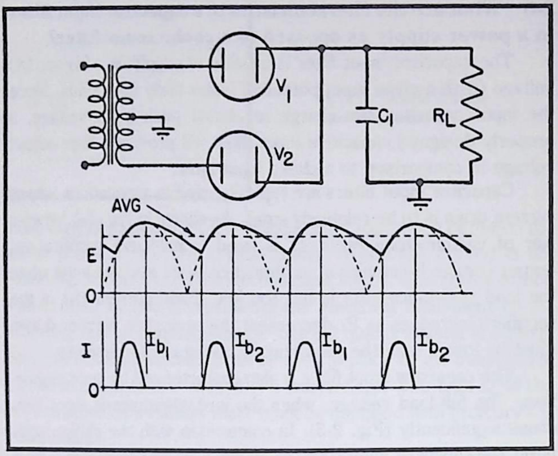


Fig. 2-3. Effect of capacitor input filter with a very low resistance.

Compared to capacitive input filter, the choke input filter will have the following characteristics:

1. Lower output voltage. In a full-wave circuit the direct-current output cannot exceed the average value of the input.
2. Higher current output. This is due to the lower peak current and higher average current of the rectifier, as illustrated in the waveform in Fig. 2-4.
3. Better regulation. There is less change from no-load to full-load conditions. Figure 2-5 shows the effect of load on the terminal voltage of both kinds of filters.

2-7 What is the definition of "voltage regulation," as applied to power supplies?

Voltage regulation is the variation of a referenced DC voltage under changing load conditions. A negligible voltage change in a B+ line during high- and low-current drains is referred to as good regulation. A power supply whose output drops significantly when a load is applied is said to have poor regulation. For this reason the term percentage of regulation is actually a misnomer, for it refers not to the percentage of regulation at all but to the percentage of error in

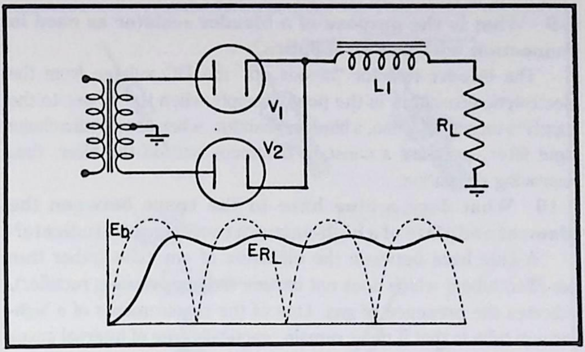


Fig. 2-4. Choke input system, showing higher current output.

regulation. If it actually did express a percentage of regulation, a high figure—such as 98% or 99%—would be desirable.

2-8 What is the principal function of a swinging choke in a filter system?

A swinging choke has a reduced air gap, which decreases its reluctance. It offers better power supply regulation than ordinary chokes; since its inductance increases with light loads and decreases with heavy loads, the output is more uniformly regulated over a broad range of changing load conditions.

Fig. 2-5. Capacitor vs choke load effects.

2-9 What is the purpose of a bleeder resistor as used in connection with power supplies?

The bleeder resistor "bleeds off" the DC voltage from the electrolytic capacitors in the power supply when the power to the supply is turned off. Also, a bleeder resistor, when used with a choke input filter, provides a constant minimum load on the filter, thus improving regulation.

2-10 What does a blue haze in the space between the filament and plate of a high-vacuum rectifier tube indicate?

A blue haze between the elements of any tube (other than gas-filled tubes, which does not include the high-vacuum rectifier), indicates the presence of gas. One of the requirements of a high-vacuum tube is that it must remain practically free of internal gases during operation. Every precaution is taken during manufacture to pump all the air from the tube. When a tube is not fully evacuated, because of a defect in manufacture or deterioration during use, the flow of current through such a tube is erratic and quite unpredictable, and the tube must be replaced.

2-11 If a high-vacuum rectifier in a high-voltage power supply should suddenly show severe internal sparking and then fail to operate, what elements of the rectifier should be checked for possible failure before installing a new rectifier tube?

Sparking in a high-vacuum rectifier is a symptom of excessive current and is often indicative of a short circuit. Before replacing the tube, the filter capacitors should be checked, as should the B+ supply line feeding the load. Occasionally, bleeder resistors change value and draw excessive current, but this is rare. The first step should be to remove the load from the B+ line to ground, with the rectifier tubes out of the circuit. If a dead short is still indicated, the problem is most likely a shorted electrolytic, which is most often caused by applying voltages in excess of the electrolytic capacitors' rated maximum working voltage.

2-12 If the plate (or plates) of a rectifier tube suddenly becomes red hot, what might be the cause?

A red-hot plate indicates excessive current. The most frequent cause of excessive plate current is too low a resistance between B+ and ground. The short could be anywhere between the cathode of the rectifiers and the output terminal of the disconnected B+ supply.

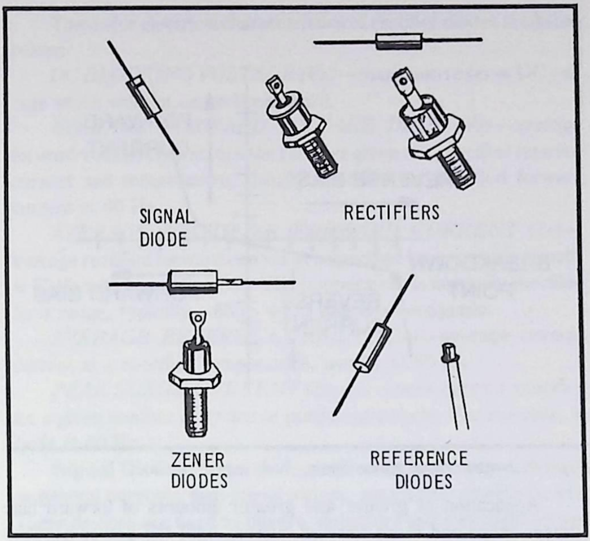


Fig. 2-6. Diode pictorials.

If the condition persists after the B+ line has been disconnected from the cathode, the condition is probably attributable to a shorted rectifier filament winding in the high voltage transformer.

2-13 Discuss the applications and electrical characteristics of rectifier, signal, and zener diodes.

Pictorial representations of various diodes are shown in Fig. 2-6. This is a very limited representation of the wide assortment in case design. However, the shape of characteristic curves of these diodes is very similar; primarily, current and voltage limits and relationships are different.

Figure 2-7 shows a typical curve of a junction diode. The graph shows two different kinds of bias. Bias in the PN junction is the difference in potential between the anode (P material) and the cathode (N material). Forward bias is the application of a voltage between N and P material, where the P material is positive with respect to the N material. When the P material becomes negative with respect to the N material, the junction is reverse biased.

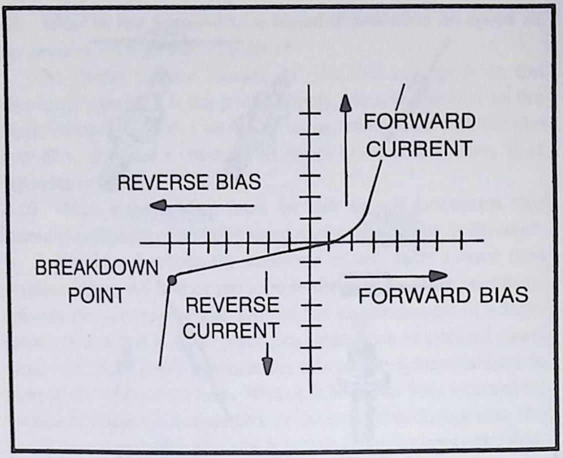


Fig. 2-7. Junction diode typical curve.

Application of greater and greater amounts of forward bias causes more and more forward current until the power-handling capability of the diode is exceeded, unless limited by external circuitry. Small amounts of forward bias cause very little current flow until the internal barrier potential is overcome. The potential difference varies from diode to diode, but is usually no more than a few tenths of a volt. Reverse bias produces a very small amount of reverse current until the breakdown point is reached, then an increase in reverse bias will cause a larger increase in reverse current.

Therefore, if breakdown is not exceeded, the ratio of forward current to reverse current is large—for example, milliamperes to microamperes or amperes to milliamperes. Changes in temperature may cause alterations in the characteristic curve, such as: slope of curve at any point, breakdown point, amount of reverse current, etc.

Rectifier Diodes: Rectifier diodes are used primarily in power supplies. These diodes are primarily of the silicon type because of this material's inherent reliability and higher overall performance compared to other materials. Silicon allows higher forward conductance, lower reverse leakage current and operation at higher temperatures compared to other materials.

The major electrical characteristics of rectifier diodes are listed below:

DC BLOCKING VOLTAGE (V_R)—maximum reverse DC voltage which will not cause breakdown.

AVERAGE FORWARD VOLTAGE DROP (V_F)—average forward voltage drop across the rectifier given at a specified forward current and temperature, usually specified for rectified forward current at 60 Hz.

AVERAGE RECTIFIER FORWARD CURRENT (I_F)—average rectified forward current at a specified temperature, usually at 60 Hz with a resistive load. The temperature is normally specified for a range, typically −65 to +175 degrees centigrade.

AVERAGE REVERSE CURRENT (I_R)—average reverse current at a specified temperature, usually at 60 Hz.

PEAK SURGE CURRENT (I_{SURGE})—peak current specified for a given number of cycles or portion of a cycle. For example, ½ cycle at 60 Hz.

Signal Diodes: Signal diodes fall into various categories, such as general purpose, high-speed switch, parametric amplifiers, etc. These devices are used as mixers, detectors and switches, as well as in many other applications.

Signal diode major electrical characteristics are:

PEAK REVERSE VOLTAGE (PRV)—maximum reverse voltage which can be applied before reaching the breakdown point.

REVERSE CURRENT (I_R)—small value of direct current that flows when a semiconductor diode has reverse bias.

MAXIMUM FORWARD VOLTAGE DROP AT INDICATED FORWARD CURRENT (V_F *at* I_F)—maximum forward voltage drop across the diode at the indicated forward current.

REVERSE RECOVERY TIME (t_{rr})—time required for reverse current to decrease from a value equal to the forward current to a value equal to I_R when a step function of voltage is applied.

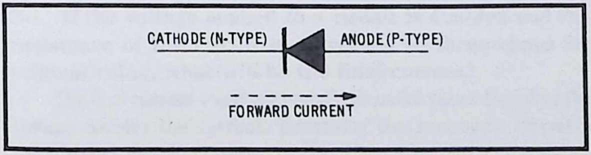


Fig. 2-8. Rectifier and signal diode schematic representation.

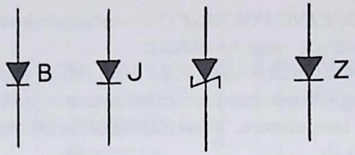


Fig. 2-9. Zener diode schematic representations.

The schematic diagram for the rectifier and signal diode is shown in Fig. 2-8. Forward current flows into the point of the arrow and reverse current is with the arrow.

Zener Diodes: The zener diode is unique compared to other diodes in that it is designed to operate reverse biased in the avalanche or breakdown region. The device is used as a regulator, clipper, coupling device and in other functions.

The major electrical characteristics of zener diodes are:

NOMINAL ZENER BREAKDOWN $V_{Z(NOM)}$—sometimes a $V_{Z(MAX)}$ and $V_{Z(MIN)}$ are used to set absolute limits between which breakdown will occur.

MAXIMUM POWER DISSIPATION (P_D)—maximum power the device is capable of handling. Since voltage is constant, here is a corresponding current maximum (I_{ZM}).

Schematic diagrams of the zener are shown in Fig. 2-9. Zener current flows in the direction of the arrow. In many schematics a distinction is not made for this diode—a signal diode symbol is used.

Chapter 3
Practical Electronic Circuits

You are not expected to know a great deal about various electronic circuits used in amateur radio to pass the Novice class exam, but you must be familiar with a few basic circuits. In this chapter you will learn how to calculate resistances and capacitances in a given circuit. You will learn why filters are used in electronic circuits. You will learn how to draw simple power supply circuits, amplifiers, and oscillators. Finally, you are exposed to various methods of keying transmitters.

A large portion of the chapter is devoted to oscillator circuits. One the examination, you may be asked about only one type of oscillator, but which one? Here is where you will have to memorize circuits. And this does take a little hard study. Look at how the transistors (or electron tubes) are connected in the circuit, and be able to identify that circuit by its name (Hartley, TPTG, Colpitts, etc.). The answers given explain the operation of each circuit.

A sample question prepared by the FCC appears at the end of this chapter.

3-1 If the voltage applied to a circuit is doubled and the resistance of the circuit is increased to three times its original value, what will be the final current?

The final current value will be 2/3 the initial value. Doubling the voltage doubles the current; increasing the resistance causes a reciprocal change in current.

3-2 If a vacuum tube having a filament rated at 0.25A and 5.0V is to be operated from a 6V battery, what is the value of the necessary series dropping resistor?

The resistor must drop 1V; the current through the resistor will be 0.25A. We thus have two of the values necessary to calculate the drop per Ohm's law: E = 1.0, I = 0.25. In this case E divided by I is 4; so the value of the resistor is 4Ω.

3-3 If resistors of 3, 5, and 15 ohms are connected in parallel, what is the total resistance?

The value of parallel resistance is equal to the reciprocal of the sum of the individual reciprocal values, or:

$$R_t = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}}$$

$$= \frac{1}{\frac{1}{3} + \frac{1}{5} + \frac{1}{15}}$$

$$= \frac{1}{\frac{5}{15} + \frac{3}{15} + \frac{1}{15}}$$

$$= \frac{1}{\frac{9}{15}} = \frac{15}{9}$$

= 1 2/3 ohms

3-4 If a 30 ohm resistor is replaced with two 15 ohm resistors in series, what would be the effect on total circuit resistance?

There is no effect. In a series circuit, the total circuit resistance (R_t) is equal to the sum of the individual resistances. As an equation: $R_t = R_1 + R_2 + R_3 + \ldots R_n$. The subscript n denotes any number of additional resistances that might be in the equation.

Therefore, replacing the 30 ohm resistor with two 15 ohm resistors in series will not change the total circuit resistance.

3-5 Given three parallel resistors of 20 ohms, 30 ohms, and 40 ohms, find the equivalent resistance using the reciprocal equation.

The reciprocal formula is:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \cdots \frac{1}{R_n}}$$

Substitute:

$$R_{eq} = \frac{1}{\frac{1}{20} + \frac{1}{30} + \frac{1}{40}}$$

find LCD:

$$R_{eq} = \frac{1}{\frac{6}{120} + \frac{4}{120} + \frac{3}{120}} = \frac{1}{\frac{13}{120}}$$

invert:

$$R_{eq} = \frac{120}{13} = 9.23 \text{ ohms}$$

3-6 What is the equivalent resistance of a 20 ohm and a 30 ohm resistor connected in parallel?

A convenient formula for finding the equivalent resistance of *two* parallel resistors can be derived from the equation shown below:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

Finding the LCD:

$$R_t = \cfrac{1}{\cfrac{R_2 + R_1}{R_1 \times R_2}}$$

Taking the reciprocal:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

This equation, called the product over the sum formula, is used so frequently it should be committed to memory.

Given: $R_1 = 20$

$R_2 = 30$

Find: $R_{eq} = ?$

Solution:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

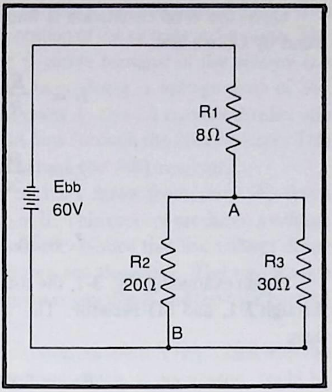
$$R_t = \frac{20 \times 30}{20 + 30}$$

$R_t = 12$ ohms

3-7 A milliameter with a full-scale deflection of 1 mA and a resistance of 25Ωwas used to measure an unknown current by shunting the meter with a 4Ωresistor. If a meter indicates 0.4 mA, what would be the actual current value?

The current in the individual resistances will be inversely proportional to the ratio of resistance values. The ratio of values is 25:4, or 6.25; thus the value through the shunt will be 6.25 times the value indicated on the meter, or 6.25 × 0.4 = 2.5 mA. The value

Fig. 3-1. Graphic for Question 3-8.



through the meter is additive with the paralleled value, or 0.4 + 2.5 = 2.9 mA.

3-8 In the circuit shown in Fig. 3-1, solve for the total circuit resistance; the total circuit current; the voltage across each resistor; and the current through each resistor.

Close examination of the circuit shows that the only quantity that can be computed with the given information is the equivalent resistance of R2 and R3. However, once this quantity is known, it can be added to R1 to obtain the total resistance of the circuit.

The formula for finding the equivalent resistance of the *two* parallel resistors is:

$$R_{eq} = \frac{R_2 \times R_3}{R_2 + R_3}$$

Thus:

$$R_t = R1 + R_{eq}$$

or:

$$R_t = R1 + \frac{R2\,R3}{R2 + R3}$$

$$R_t = 8 + \frac{20 \times 30}{20 + 30}$$

$$R_t = 8 + 12$$

$$R_t = 20\Omega$$

Once the total resistance is known, the total current can be found by Ohm's law.

$$I_t = \frac{E_t}{R_t}$$

$$I_t = \frac{60}{20}$$

$$I_t = 3A$$

Again examining Fig. 3-1, the total current of 3A is seen to flow through $R1$, and 8Ω resistor. The voltage across this resistor is thus:

$$E_{R1} = I_t R1$$

$$E_{R1} = 3 \times 8$$

$$E_{R1} = 24V$$

Since 60V are applied to the circuit and 24 of these 60V are dropped across $R1$, the remaining 36V must be dropped across the two parallel resistors $R2$ and $R3$ (Kirchhoff's voltage law). The currents through $R2$ and $R3$ are:

$$I_{R2} = \frac{E_{R2}}{R2}$$

$$I_{R2} = \frac{36}{20}$$

$$I_{R2} = 1.8 \text{ amps}$$

and:

$$I_{R3} = \frac{E_{R3}}{R3}$$

$$I_{R3} = \frac{36}{30}$$

$$I_{R3} = 1.2 \text{ amps}$$

Having computed all the currents and voltages of Fig. 3-1, a complete description of the operation of the circuit can be made. The total current of 3A leaves the negative terminal of the battery and flows through the 8Ω resistor. In so doing, a voltage drop of 24V occurs across this resistor. At point A, this 3A current divides into two currents. Of the total, 1.8A flow through the 20Ω resistor. This current produces a 36V drop across the 20Ω resistor.

The remaining current of 1.2A flows from point A, down through the 30Ω resistor to point B. This current produces a voltage drop of 36V across the 30Ω resistor. Notice that the voltage drops across the 20Ω and 30Ω resistors are the same. The two branch currents of 1.8A and 1.2A combine at junction B and the total current of 3A flows back to the source.

The action of the circuit has been completely described with the exception of the power dissipations which, if necessary, could be computed using methods previously shown.

The combination circuit is not difficult to solve. The key to its solution lies in knowing the order in which the steps of the solution must be accomplished.

3-9 If capacitors of 1, 3 and 5μF are connected in parallel, what is the total capacitance?

The value would be $9\mu F$. Capacitances in parallel are additive in precisely the same way as resistors in series.

3-10 What would be the total capacitance of 5, 3 and 7 μF capacitors in series?

Based on the equation of question 1-37, the value would be 1.48 μF. The idea is to convert the fractional values to a common denominator so they may be added. If the values are multiplied together to get a common denominator of 105, the reciprocal values of the capacitance will be 21/105, 35/105, and 15/105. These add to 71/105, or 0.676. The reciprocal of 0.676 is 1.48.

3-11 Having available a number of capacitors rated at 2 μF, 400V each, how many would be necessary to obtain a combination rated at 1.5 μF, 1.6 kV?

Twelve. Capacitors may be placed in series for equal distribution of voltage, but the capacitance of the combination of four 2 μF capacitors in series would be only 0.5 μF. Since paralleling

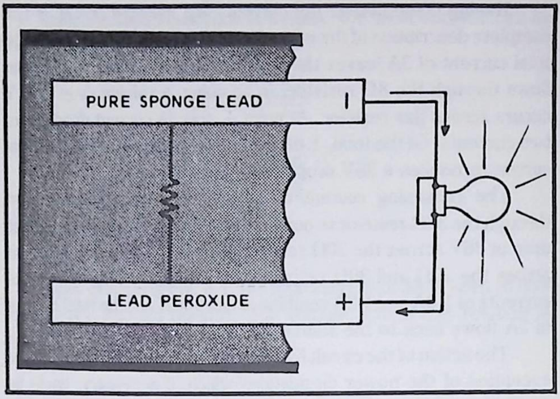


Fig. 3-2. The battery's internal resistance must be calculated.

capacitors adds capacitance values, three such series strings would result in a total value of 1.5 μF, 1.6 kV.

When connecting capacitors in series, it is a good idea to place a high-value resistor across each capacitor. As long as all resistors are the same value, the voltage across the capacitors will be evenly distributed (neglecting any excessive leakage).

3-12 A hypothetical 6V storage battery has an internal resistance of 0.1Ω. What current will flow when a 3W lamp of the proper voltage rating is connected?

Remember, the internal resistance of the battery must be taken into consideration, because it becomes part of the circuit, just as the resistor is shown to be part of the battery in Fig. 3-2. The 3W resistor (the lamp) would draw 0.5A from a 6V source ($I = W/E$), but the source voltage is dropped because of the 0.1Ω resistance. Based on the wattage rating of the lamp, its resistance is 12Ω ($R = E^2/P$); thus the series resistance totals 12.0Ω + 0.1Ω, or 12.1Ω. From Ohm's law, then, current equals 6 divided by 12.1 ($I = E/R$), or 0.496A (496 mA).

3-13 In general, why are filters used? Why are bandstop, high-pass, and low-pass filters used? Draw schematic diagrams of the most commonly used filters.

Filters are used to control the frequencies to be transferred from one circuit to another, much as filtration paper is used to control the amount of impurities circulating in an automobile's engine oil.

A bandstop filter, also referred to as a band rejection filter, is shown in Fig. 3-3A. Here, the band of resonant frequencies finds the series resonant circuits (S and S') to be a low-impedance path and the parallel resonant circuit (P) a high-impedance path; thus, the resonant band of frequencies is rejected, or shunted to ground. All other frequencies find S and S' high-impedance paths and P a low-impedance path; accordingly, they pass from input to output with little opposition.

In Fig. 3-3B the resonant band of frequencies finds the parallel resonant circuit (P and P') high-impedance paths and the series resonant circuit (S) a low-impedance path. Thus, the resonant band of frequencies is passed from input to output with little opposition, while all other frequencies find P and P' low-impedance paths and S a high-impedance path. Accordingly, frequencies other than those desired are rejected.

Figure 3-4 shows the basic low-pass and high-pass filters. In Fig. 3-4A high frequencies at the input meet a relatively high induc-

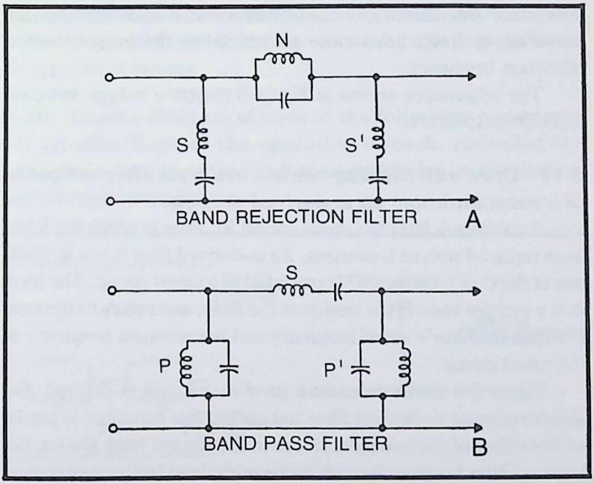


Fig. 3-3. Band rejection filter (A) and band pass filter (B).

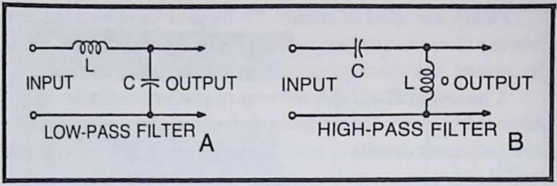


Fig. 3-4. Low pass and high pass filters.

tive reactance in L and a low capacitive reactance in C, so high frequrncies are stopped by L and short-circuited by C. Low frequrncies meet little opposition in L and high opposition in C. This is a low-pass filter, typically used in the RF output circuit of transmitters to prevent the transfer of harmonics and spurious frequencies.

Figure 3-4B shows the basic high-pass filter. The theory of operation is basically the same as for the low-pass filter, except that the filter offers little opposition to frequencies above the design frequency and high opposition to frequencies below the design frequency. High-pass filters are used in such places as television receivers to prevent the passage into the TV set of frequencies below the television band. Amateur and other radio services might otherwise cause interference to these receivers, if such services are operating on frequencies close to but below the lowest desired television frequency.

The schematics shown in Fig. 3-5 illustrate π-type low-pass and high-pass filters.

3-14 Draw a circuit diagram of a low-pass filter composed of a constant-k and an m-derived section.

A constant-k filter is a conventional RC filter in which the R has been replaced with an L element. An m-derived filter is one in which one of the C or L elements is converted to a tuned circuit. The term m is a variable used in the design of the filter, and refers to the ratio between the filter's cutoff frequency and the resonant frequency of the tuned circuit.

Figure 3-6 shows constant-k parallel-resonant m-derived, and series-resonant m-derived filter networks. If a capacitor is placed across either of the two inductances in the top left filter shown, the low-pass filter becomes a combination m-derived (with tuned circuit) and constant-k (series L, shunted C) network.

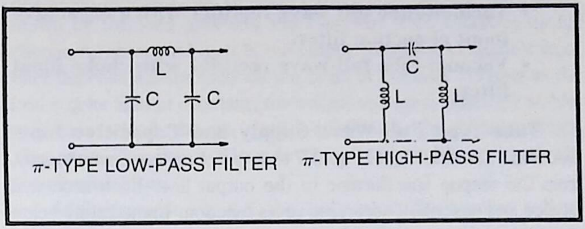


Fig. 3-5. Pi-type filters.

If both inductors are shunted with a capacitance, the filter becomes an m-derived filter, as shown in the lower left sketch. It takes a complete series L, parallel C, parallel L to make a constant-k section.

3-15 List the main advantages of a full-wave rectifier as compared to a half-wave rectifier.

The ripple frequency of the pulsating DC output signal from a full-wave rectifier is twice that of the half-wave rectifier. Thus the output voltage is easier to filter. Also, since the transformer supplying the rectifier is used for a full cycle (rather than for one-half cycle), both voltage and circuit efficiency are increased with no performance or operational penalty.

3-16 Draw a diagram of each of the following power supply circuits. Explain the operation of each, including the relative input and output voltage amplitudes, waveshapes, and current waveforms.

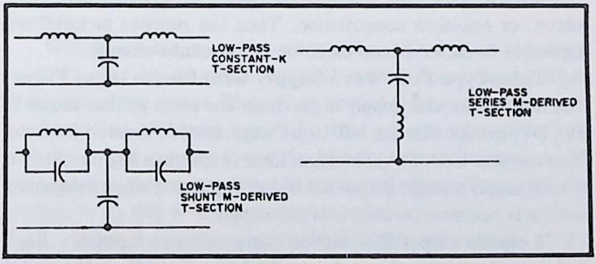


Fig. 3-6. Low-pass filters with constant-k and an m-derived section.

- **Vacuum-tube full-wave rectifier with a capacitive input pi-section filter.**
- **Vacuum-tube full-wave rectifier with choke input filter.**

Tube-Type Full-Wave Supply and Capacitive Input Section: The drawing of Fig. 3-7 shows a complete power supply, from the stepup transformer to the output line. Each section is labeled and described according to its function. Immediately below the diagram sections are waveforms that represent the output voltage of each section. As shown, the transformer section of the supply is driven from the 115V primary power line. The transformer is shown with windings—one for the rectifier's filaments and the other for the high voltage.

The rectifier stage allows current to pass in one direction only. The pi-section filter is named because of its shape; notice the resemblance between the filter and the Greek letter π. (The regulator and voltage divider sections, though not required by the question, are presented to allow a better understanding of power supply circuits.)

Note that each section is applicable to virtually any power supply. For example, the transformer section can be used for any of the various power supply configurations; and the filter, a capacitive input type, is applicable to all power supply circuits, be they half-wave or full-wave. The explanations of the circuit functions shown in the drawing are applicable to all other illustrated power supply types except as noted.

Figure 3-8 illustrates the basic power supply circuits. It should be noted that the diode symbol—the arrow with a perpendicular line crossing the point—may be used for diodes of either vacuum-tube, silicon, or selenium construction. Thus the supplies pictured are applicable to either silicon diode or vacuum-tube circuits.

Tube-Type Full-Wave Supply with Choke Input Filter: The diagram for this supply is precisely the same as that shown in Fig. 3-7, except that the left 10 μF capacitor is removed from the filter section. Use of a choke input filter results in a slight reduction of total supply voltage output but better regulation when a regulator section is not incorporated into the supply.

A capacitor input filter with no load produces a terminal voltage that is nearly equal to the peak value of the applied AC. As the load is

increased, however, the terminal voltage falls, because the current drawn by the load prevents the capacitor from retaining its full charge. As shown in Fig. 3-9, the output voltage of a capacitor input filter depends substantially on the drain of the load. As long as the load is quite light or constant, the output voltage is relatively stable; variations in load, though, cause variations in the output voltage. **The capacitor input filter is thus said to have relatively poor regulation.**

As illustrated in Fig. 3-9, the choke input filter's output voltage is relatively constant as long as the load is above a certain minimum value. Since the output voltage remains essentially the same over a wide range of current drains, **the choke input filter is said to have good regulation.**

3-17 Draw a simple schematic indicating the internal resistance of a battery with a resistive load. Explain.

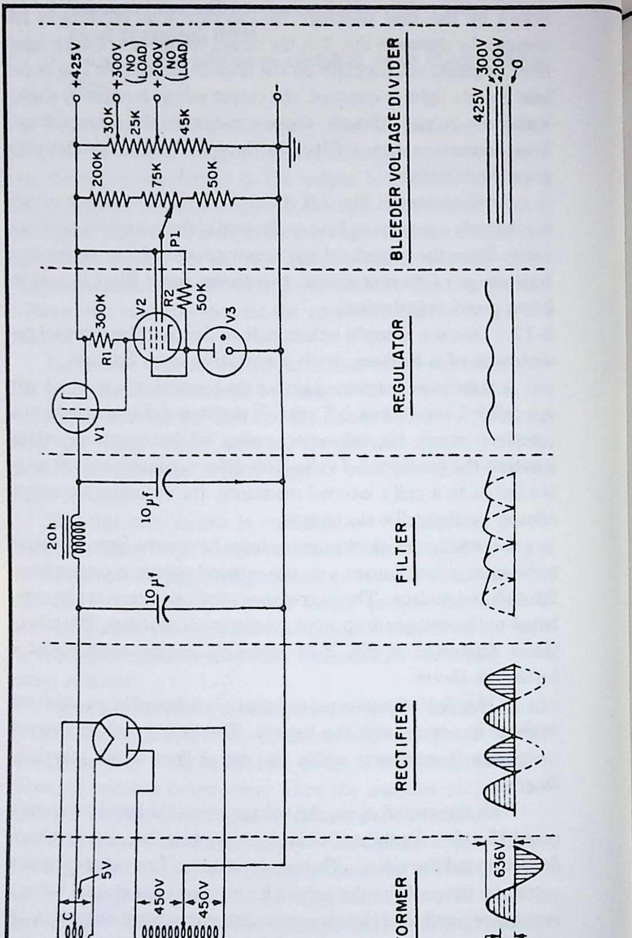
A voltmeter connected across the terminals of a good 1.5 volt dry cell will read about 1.5 volts. If the same cell is inserted into a complete circuit, the voltmeter reading will decrease to something less than the previous 1.5 volts. This difference in terminal voltage is attributed to a cell's internal resistance, the opposition to current offered by the cell's electrolyte.

All sources of electromotive force have some form of internal resistance, which causes a drop in terminal voltage as current flows through the source. The decrease in terminal voltage can be attributed to the voltage drop across the internal resistance. This principle is illustrated in Fig. 3-10 where the internal resistance of a battery is shown.

In Fig. 3-10 the internal resistance is indicated by an additional resistor in series with the battery. The battery with its internal resistance is enclosed within the dotted lines of the schematic diagram.

With the switch open, the voltage across the battery terminals reads 15 volts. As the switch is closed, current flow causes voltage drops around the circuit. The circuit current of two amperes causes a voltage drop of 2 volts across R_1, the one ohm internal battery resistance, and thereby drops the battery terminal voltage to 13 volts. Internal resistance cannot be measured with an ohmmeter. An attempt to do this would damage the meter.

3-18 Draw a simple schematic diagram of a single stage transistorized audio amplifier.



TRANSFORMER
RECTIFIER
FILTER
REGULATOR
BLEEDER VOLTAGE DIVIDER
115 V
163V
636V
C
5V
450V
450V
20h
10μf
10μf
V1
R1
300K
V2
R2
50K
V3
P1
200K
75K
50K
30K
25K
45K
+425V
+300V (NO LOAD)
+200V (NO LOAD)
425V
300V
200V
0

Low voltage is stepped up by the transformer from 115 volts to 900 volts. Center tap provides a dividing point so that 450 volts are applied to each section of the 5U4G rectifier. The ends of the transformer alternately become positive and negative.

Center tap C on heater winding is used to force plate current to divide equally in each filament lead. If there is no center tap, a voltage divider of two equal 50 ohm resistors may be put across the secondary to produce the same effect.

Alternately positive and negative voltage is applied to the plates of the rectifier.

The two plates conduct alternately as each plate is made positive in turn by the secondary of the transformer. Pulses of current flow from the filament line to each plate in turn. The plates alternately become positive and negative with the applied a. c., but the filament line will show a one-directional flow.

Capacitors charge when the rectifier conducts, and they discharge through the bleeder resistor when the tube is not conducting.

Choke builds up a magnetic field when the tube draws current. The field collapses as current decreases, tending to keep a constant current flowing in the same direction through the bleeder resistor and the load.

Capacitor input (illustrated) gives higher voltage output with low current loads.

Choke input gives steadier output with less ripple under load conditions.

If the load draws more current or if the a-c input voltage falls, the terminal voltage of the power supply falls.

Resistor R1, tube V2, and gas-tube V3 are in series across the rectifier terminals. V3 holds the cathode of V2 at a constant positive potential with respect to ground, and setting of P1 determines bias on V2. A fall in terminal voltage causes more negative bias on V2, less current through V2, hence, less current through R1. Less IR drop across R1 causes less negative bias on V1. V1, then acts as a lower value resistor, and terminal voltage decrease is checked.

As a bleeder, the resistor is for safety to discharge the capacitors when power is removed.

As a load resistor, it acts as a stabilizer to protect the voltage regulator at no load, and to improve the regulation.

A voltage divider meets the requirements of a load resistor and a bleeder, but in addition has taps placed at intervals for voltage at less than the maximum.

It is usually grounded at the lower end but may be grounded at any higher point to get a negative output.

Fig. 3-7. Power supply schematic.

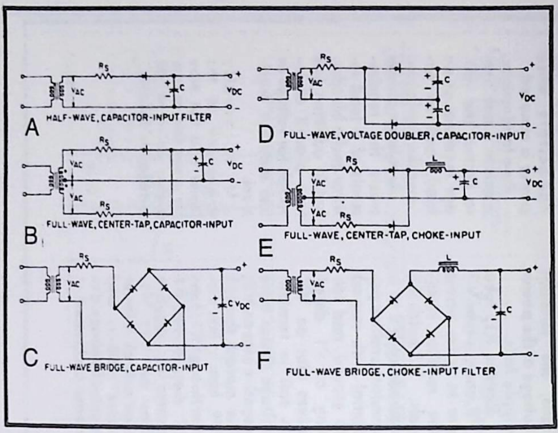


Fig. 3-8. Basic power supply circuits.

The circuit of Fig. 3-11 shows a basic single stage *class A* audio amplifier using a transistor as the amplifying device. The input will be a low amplitude audio voltage (normally in the millivolt range) which will be amplified by Q1 and coupled either to another voltage amplifier or, if sufficient amplification has been obtained in this stage, to a power amplifier. Q1 is a PNP transistor in the common-emitter configuration. Resistor R_L serves as the collector load resistor, R_E and C_E are the emitter bias stabilization network, and R_B limits the bias current and thereby establishes the operating point. The value

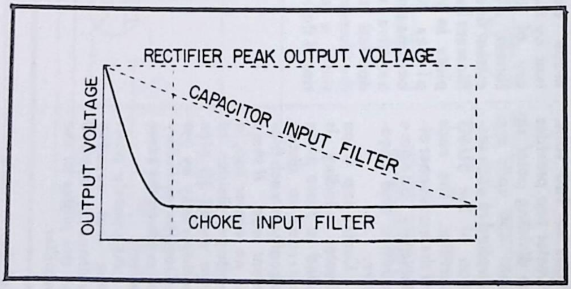


Fig. 3-9. Output voltage graph.

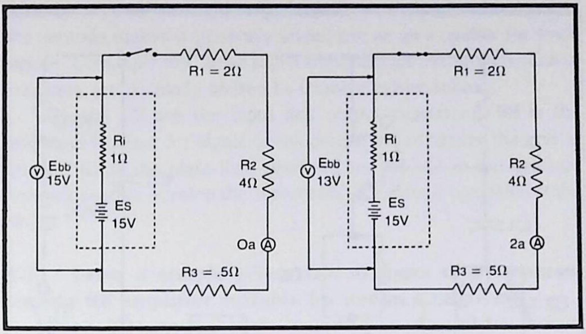


Fig. 3-10. Internal resistance of a battery.

of coupling capacitor C2 is chosen to assure good frequency response. When −Vcc is applied to the circuit, the current flow through the base-emitter junction develops a voltage which forward biases the input circuit.

3-19 Draw a simple schematic diagram of a transistorized Hartley oscillator.

The circuit shown in Fig. 3-12 is a series fed Hartley oscillator using an NPN transistor. It is designated as a series fed oscillator

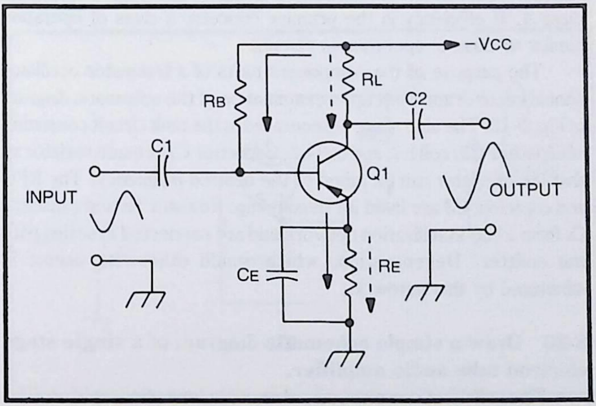


Fig. 3-11. Single stage class A audio amplifier circuit.

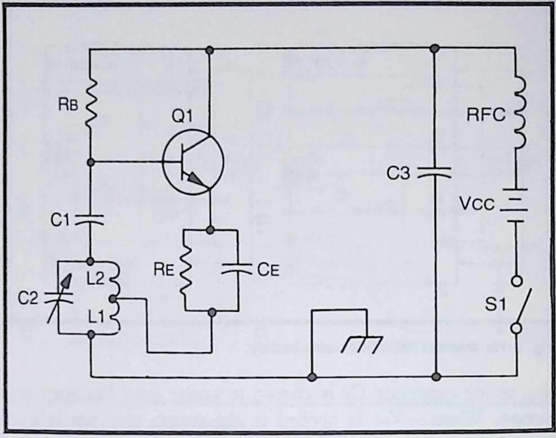


Fig. 3-12. Series fed Hartley oscillator circuit.

because the feedback component is connected in series with the power supply. This transistor oscillator can be operated *class A* or *B*.

Where stability and pureness of waveform (low harmonic content) are the major considerations, the oscillator would be operated class *A*. If efficiency is the primary concern, a class of operation similar to class *C* operation is chosen.

The purpose of the component parts of a transistor oscillator should become apparent upon examination of the schematic diagram in Fig. 3-12. The sine wave is generated in the tank circuit consisting of capacitor C2, coil L1, and coil L2. Capacitor C2 is made variable so that the oscillator can be tuned to the desired frequency. The RFC and capacitor C3 are used for decoupling. Resistor R_E and capacitor C_E form a bias stabilization network and are connected in series with the emitter. Degeneration, which would otherwise occur, is minimized by this netowrk.

3-20 Draw a simple schematic diagram of a single stage electron tube audio amplifier.

Figure 3-13 shows the basic electron tube audio amplifier. The circuit shown uses a triode as the amplifying device. While a pentode

could be used as a voltage amplifier, the normal high noise level of the pentode makes it generally unsuitable as an amplifier for small signals. Consequently, small signal amplifiers for the audio section of receivers are normally limited to triode electron tubes.

C1 and C2 are the input and output capacitors, R1 is the grid-input resistor for signal development and returning the grid to ground, R2 is the plate load resistor, and R_k—C_k is the self-bias network used to develop the correct bias for *class A* operation of the circuit.

3-21 Draw a simple schematic diagram of a common-emitter RF amplifier suitable for use in a receiver.

Figure 3-14 shows the schematic diagram of a common-emitter RF amplifier using a PNP transistor. The common-emitter configuration is used in order to take advantage of the greater gain and the simpler biasing arrangement.

At the start of the cycle of operation, the transistor is in a quiescent condition, with the collector current determined by the voltage divider resistors R1, R2, and emitter resistor R3. Current flow is from the negative terminal of the source through R1 and R2 to ground.

The values of R1, R2 and R3 are chosen so that the difference in potential between the base and emitter (forward bias) is only a few tenths of a volt, and is set at the center of the forward transfer

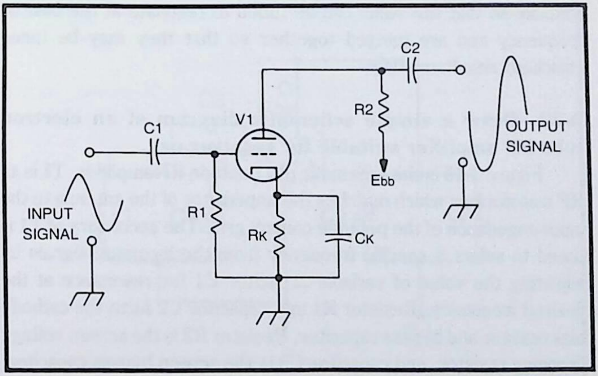


Fig. 3-13. Basic electron tube audio amplifier circuit.

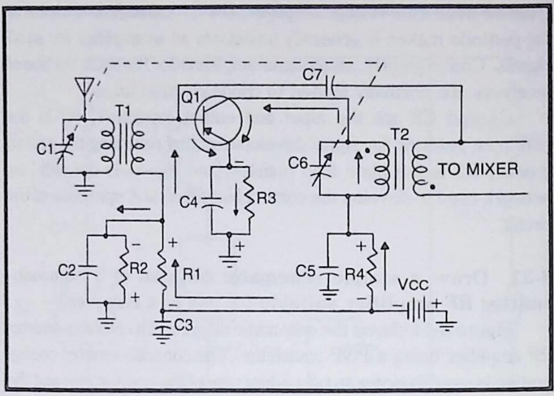


Fig. 3-14. Common-emitter RF amplifier schematic.

characteristic curve for *class A* operation. Resistor R4 determines the collector voltage for Q1 while emitter bias and temperature stablization are provided by R3. Capacitor C4 prevents degeneration across the emitter resistor by placing the emitter at a c ground. C7 is the neutralizing capacitor while capacitors C1, C2, C3 and C5 bypass the RF currents around the biasing network and power supply.

The input tank consists of C1 and the primary of T1 while C6 and the primary of T2 make up the output tank. C1 and C6 are variable so that the tanks can be tuned to resonate at the desired frequency and are ganged together so that they may be tuned (tracked) simultaneously.

3-22 Draw a simple schematic diagram of an electron tube RF amplifier suitable for receiver use.

Figure 3-15 is the schematic of a pentode RF amplifier. T1 is an RF transformer which matches the impedance of the antenna to the input impedance of the pentode control grid. The secondary of T1 is tuned to select a specific frequency from the incoming signals by adjusting the value of variable capacitor C1 for resonance at the desired frequency. Resistor R1 and capacitor C2 form the cathode bias resistor and bypass capacitor. Resistor R2 is the screen voltage dropping resistor, and capacitor C3 is the screen bypass capacitor, which stabilizes the screen voltage and prevents it from being

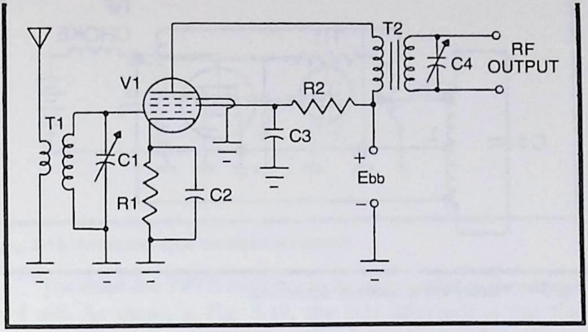


Fig. 3-15. Pentode RF amplifier schematic.

affected by the signal. The suppressor element of V1 is grounded directly. In some circuits it is connected externally to the cathode. RF transformer T2 acts as the plate load and couples the output to the next stage. The output winding is tuned by C4 to the desired RF output frequency.

3-23 Draw a simple schematic diagram showing a tuned-plate, tuned-grid (TPTG) oscillator with a series-fed plate.

Refer to Fig. 3-16. This oscillator has tuned circuits in both grid and plate circuits, and it is advantageous because it may be used

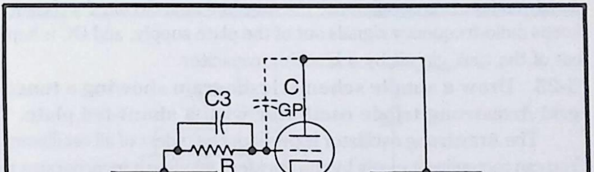


Fig. 3-16. TPTG oscillator schematic.

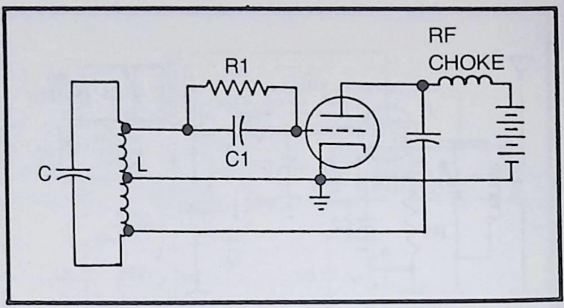


Fig. 3-17. Hartley triode oscillator schematic.

equally well at low as well as ultrahigh frequencies. Notice in the figure that the inductance in the plate tank circuit is not inductively coupled to the inductance in the grid circuit. The feedback to sustain oscillation occurs through the interelectrode capacitance of the tube from grid to plate; this is illustrated by a broken line showing the grid-to-plate capacitance (C_{gp}) inherent in the tube.

3-24 Draw a simple schematic diagram showing a Hartley triode oscillator with a shunt-fed plate.

In the shunt-fed Hartley oscillator (Fig. 3-17) direct current does not flow through any part of the tank circuit, and the plate supply voltage is in parallel with the tube and tank circuit. An rf choke keeps radio-frequency signals out of the plate supply, and DC is kept out of the tank circuit by a blocking capacitor.

3-25 Draw a simple schematic diagram showing a tuned-grid Armstrong triode oscillator with a shunt-fed plate.

The Armstrong oscillator is perhaps the oldest of all oscillators. You can recognize it easily by the "tickler" winding it incorporates to introduce feedback. In the circuit pictured in Fig. 3-18, B+ voltage is applied though an rf choke to the plate. Varying the number of turns in the tickler winding adjusts the feedback fraction. Questions on the Armstrong oscillator show up on numerous FCC tests in spite of the fact that the vacuum-tube version is virtually obsolete and the transistor equivalent is rarely seen.

3-26 Draw a simple schematic diagram showing a tuned-plate, tuned-grid oscillator (triode) with shunt-fed plate.

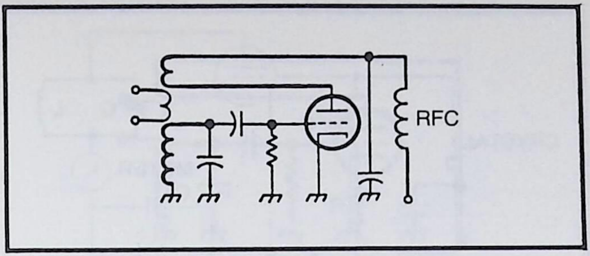


Fig. 3-18. Armstrong tiode oscillator schematic.

The shunt-fed TPTG oscillator looks very similar to the series-fed unit. As shown in Fig. 3-19, the only difference is that the shunt-fed type receives its plate voltage directly from the source (through an rf choke). The tuned circuit that makes up the plate tank connects directly to ground.

3-27 Draw a simple schematic of a crystal-controlled tube-type oscillator.

Since a quartz crystal is equivalent to a resonant circuit, it can be used in place of the usual tuned circuit as a frequency-controlling element in an oscillator. The circuit shown in Fig. 3-20 is a common triode oscillator using a quartz crystal.

3-28 Draw a simple schematic diagram showing a Colpitts oscillator (tirode) with shunt-fed plate.

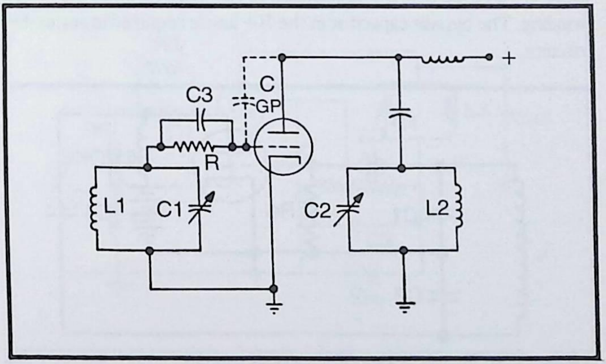


Fig. 3-19. Shunt-fed TPTG oscillator schematic.

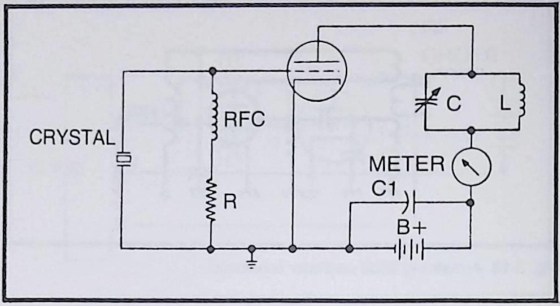


Fig. 3-20. Common triode oscillator schematic.

The Colpitts oscillator is essentially the same as the Hartley, except that a pair of capacitances in series is connected across the tank coil. The capacitive combination of C1 and C2 in Fig. 3-21 forms a voltage divider that splits the potential across the resonant circuit. The voltages at the ends of the resonant circuit are opposite in polarity with respect to the cathode and in the right phase to sustain oscillation. Total tank capacitance consists of C1 and C2; the grid-leak bias combination is made up of C3 and Rg.

3-29 Draw a simple diagram of a tuned-grid Armstrong triode oscillator with a series-fed plate.

The series circuit differs from the shunt circuit in plate supply. Note in Fig. 3-22 that B+ is supplied to the plate through the tickler winding. The bypass capacitor in the B+ line is required in series-fed circuits.

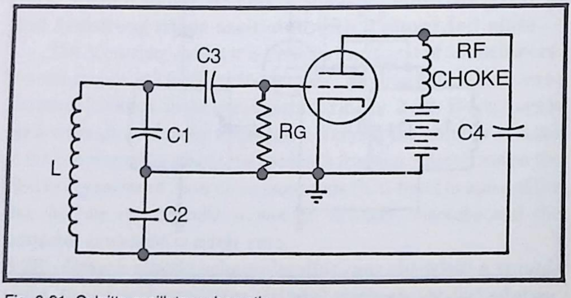


Fig. 3-21. Colpitts oscillator schematic.

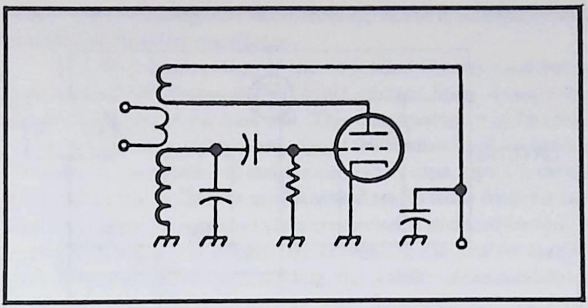


Fig. 3-22. Tuned-grid Armstrong oscillator schematic.

3-30 Draw a simple schematic diagram of an electron-coupled oscillator.

Actually a modified version of the Hartley, the electron-coupled oscillator (Fig. 3-23) combines the functions of both an oscillator and an amplifier. The control grid's tank circuit, the control and screen grids, and the cathode form a series-fed oscillator with the screen grid serving as the plate. Capacitor C2 places the screen at zero potential (rf) and, like C3, bypasses the plate supply. The output tuned circuit is in the plate circuit, so the only coupling path is the electron stream between grid tank and plate tank (hence the circuit's name).

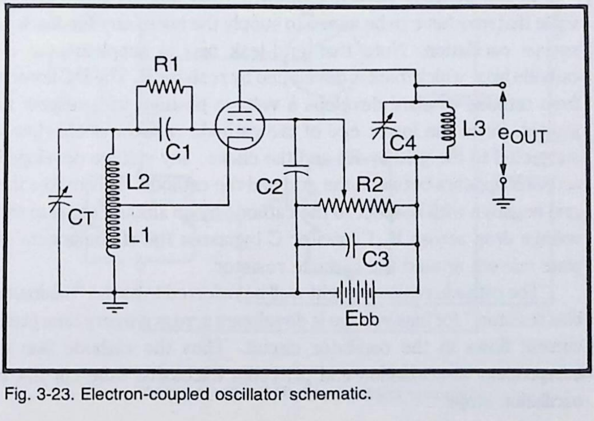


Fig. 3-23. Electron-coupled oscillator schematic.

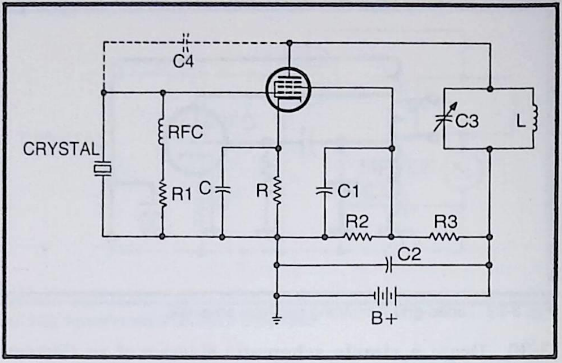


Fig. 3-24. Pentode crystal oscillator schematic.

3-31 Draw a simple schematic of a pentode crystal oscillator.

A pentode oscillator such as the one shown in Fig. 3-24 is a good deal more common than a triode crystal oscillator because it requires far less excitation to drive the tube to full power output. The battery is marked B+, and no other polarities are shown. Remember, the long parallel plates on a schematic battery symbol represent the positive ends of the battery cells.

In the pentode oscillator shown, capacitor C4 represents a value that may have to be added to supply the necessary feedback to sustain oscillation. Note that grid-leak bias is supplemented by cathode bias, which itself is developed by resistor R. The DC flowing from cathode to plate develops a voltage positive with respect to ground. Since the lower end of the cathode resistor is effectively connected to the grid by R1 and the choke, any voltage developed across R appears between the grid and the cathode. This makes the grid negative with respect to the cathode by an amount equal to the voltage drop across R. Capacitor C bypasses the rf component of plate current around the cathode resistor.

The cathode resistor might well be referred to as the "minimum bias resistor," for bias voltage is developed across it every time plate current flows in the oscillator circuit. Thus the cathode bias is independent of oscillation and prevents excessive tube current if oscillation stops.

3-32 Draw a simple schematic diagram of a transistorized shunt-fed Hartley oscillator.

The main disadvantage of the series fed Hartley oscillator is that a relatively large value of direct current flows through the feedback portion of the tank coil. This disadvantage may be overcome by a variation of the connection of the feedback coil, isolating it from the DC component of emitter current by capacitors C1 and C3 as shown in Fig. 3-25. The oscillator derives its name from the fact that the feedback component (1) is connected in shunt rather than in series with the power supply. By preventing the emitter current from flowing in the feedback winding, the stability of the oscillator is improved. Also, if emitter current were flowing through the feedback section of the tank coil, there might be a requirement for L1 to be designed differently than L2. These problems are not encountered with the shunt fed Hartley oscillator.

3-33 Draw a simple schematic diagram of a transistorized Colpitts oscillator.

Figure 3-26 shows the schematic diagram of the transistorized Colpitts oscillator. The tank circuit is composed of a variable tank

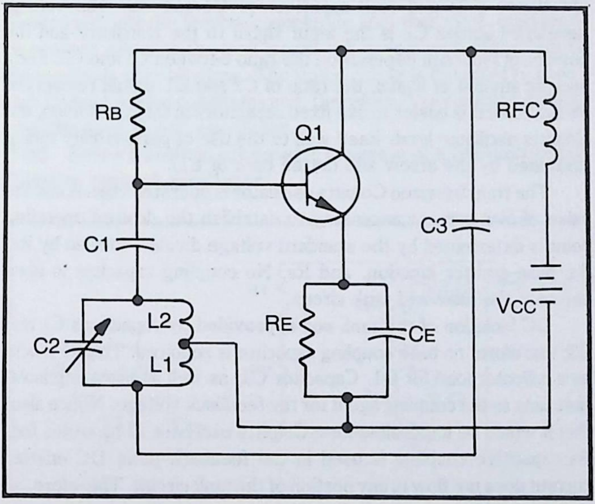


Fig. 3-25. Transistorized shunt-fed Hartley oscillator schematic.

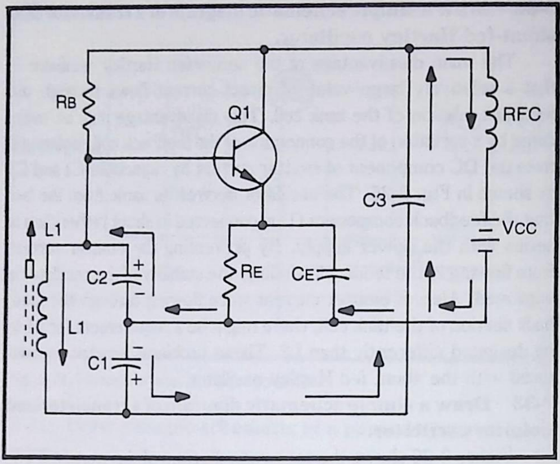


Fig. 3-26. Transistorized Colpitts oscillator schematic.

inductance (L1) and tank capacitances C1 and C2. The voltage developed across C2 is the input signal to the transistor and the amount of feedback depends on the ratio between C1 and C2. For a specific amount of signal, the ratio of C2 and C1 should remain the same. Since it is easier to use fixed capacitors in this application, the Colpitts oscillator lends itself well to the use of permeability tuning (indicated by the arrow and dotted core of L1).

The transistorized Colpitts oscillator is operated class A and the value of bias current necessary to establish the desired operating point is determined by the standard voltage divider, formed by R_E, the base-emitter junction, and R_B. No coupling capacitor is used between the base and tank circuit.

DC isolation of the tank coil is provided by capacitors C1 and C3; therefore, no base coupling capacitor is required. The RFC acts as a collector load for Q1. Capacitor C3, as well as providing isolation, acts as the coupling agent for the feedback voltage. Notice also, that it would be impossible for a Colpitts oscillator to be series fed. As capacitive coupling is used in the feedback path, DC emitter current does not flow in any portion of the tank circuit. Therefore, all Colpitts oscillators will be *shunt fed*.

3-34 Draw a simple schematic diagram of a transistorized Clapp oscillator.

The Clapp oscillator circuit is considered to be a variation of the Colplitts circuit. While either of the three transistor configurations may be used, the common-emitter configuration is the most common and is shown in Fig. 3-27.

The circuit utilizes the stabilizing effect of a series-resonant tuned tank circuit, loosely coupled to the feedback loop, to provide good stability. It also offers capacitive tuning using only one capacitor, which will not affect the feedback ratio.

In the resonant tank circuit, tuning is accomplished by a capacitor (C3) which is essentially the sum of series capacitors C1, C2 and C3. Since the total value of series capacitors is always less than the value of the smallest capacitor, it can be seen that when C1 and C2 are much larger than C3, the effective tuning capacitance is essentially the capacitance of C3 alone. Thus, the series resonant circuit consisting of L and C3 is the basic frequency determining circuit.

Since the tank circuit is controlled by L and C3, it should be clear that the feedback voltage divider (which consists of C1 and C2) determines only the feedback amplitude and, therefore, changes of component values in the tank circuit will have a negligible effect on the amplitude of oscillations. The tuned circuit is designed to have a high Q under loaded conditions and, therefore, has a greater stability than the basic Colpitts oscillator.

3-35 Draw a simple schematic diagram of a transistorized Colpitts crystal oscillator.

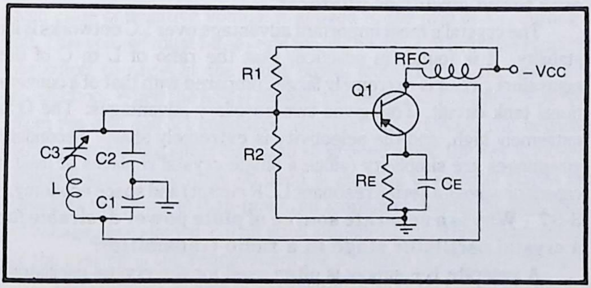


Fig. 3-27. Transistorized Clapp oscillator schematic.

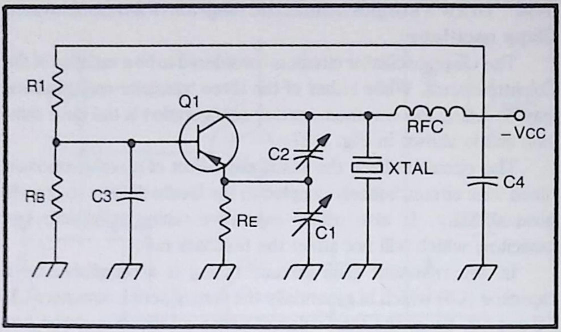


Fig. 3-28. Transistorized Colpitts crystal oscillator schematic.

The Colpitts crystal oscillator (Fig. 3-28) is used primarily at the higher radio frequencies as an extremely stable oscillator. However, it may also be used at low and medium radio frequencies. This circuit uses the piezoelectric effect of a quartz crystal to control the oscillator frequency. Feedback is provided through a capacitive voltage divider arrangement, which is usually external, but it may be provided through the transistor element capacitances. This circuit does not normally utilize a tuned tank circuit, but a tank circuit may be required in special applications. The Colpitts crystal oscillator operates similar to class C in those circuits where waveform linearity is not important, and class A when good waveform linearity is required.

3-36 What are the principal advantages of crystal control over tuned-circuit oscillators?

The crystal's most important advantage over LC networks is its stability. It is found, in practice, that the ratio of L to C of the equivalent circuit is extremely large compared with that of a conventional tank circuit. This gives two corollary advantages: The Q is extremely high, and the selectivity is extremely sharp. Secondary advantages are simplicity (since a single crystal replaces at least a capacitor across a series resonant LCR circuit) and space economy.

3-37 Why is a separate source of plate power desirable for a crystal oscillator stage in a radio transmitter?

A separate B+ supply is often used for the crystal oscillator's plate circuit, so that the tube's operation will be independent of the

loads represented by other circuits within the transmitter. Unless plate voltages are well regulated, they can drop at the source when high current demands are imposed on them. An oscillator's frequency shifts when its plate voltage changes. It is not uncommon for an AM transmitter to produce a frequency-modulated signal when the same power source is used to provide plate B+ for the final amplifier, modulator, and oscillator. In such a case the modulator draws maximum current on voice peaks, and the transmitter's total power output increases significantly. When this power drain causes a drop in the plate voltage of an AM transmitter, undesired frequency modulation is the result.

3-38 Draw simple schematic diagrams of blocked-base grid keying, cathode keying, and screen-grid keying.

In CW radiotelegraph transmission, the carrier is turned on and off to form the dots and dashes of transmitted code characters. Turning on and off the *transmitter* for this purpose is called *keying*.

One method of keying is to turn the *oscillator* on and off. This may be accomplished by opening and closing the plate or cathode circuit with a key. The oscillator should be absolutely stable while keyed. If it is not stable, frequency shifts, causing a varying note (chirp) which makes the signal difficult to copy.

Another method of keying is **blocked-base grid keying,** as shown in Fig. 3-29. Figure 3-29A is the schematic of a transistor RF amplifier showing blocked-base keying. With the key open, the positive supply provides reverse bias to the emitter-base junction, cutting off Q1. When the key is closed, reverse bias will be removed from the emitter base junction, and Q1 will conduct.

In the electron tube circuit of Fig. 3-29B, with the key open, a high value of negative voltage is applied to the grid of V1, cutting it off. This voltage must be several times the value of grid bias required for cutoff to prevent the input signal from driving the tube into conduction. When the key is closed, the negative voltage is removed from the grid and V1 conducts. Resistor R2 prevents the negative supply from being short circuited to ground when the key is closed. Blocked-grid keying may be used in any one of several stages but presents problems in high-powered amplifiers due to the high value of voltage necessary to cut off such amplifiers. Another disadvantage of the system is the requirement for a source of negative voltage.

The amplifier stages of a transmitter may be keyed by opening and closing the plate or **cathode** circuit. The key is rarely placed in

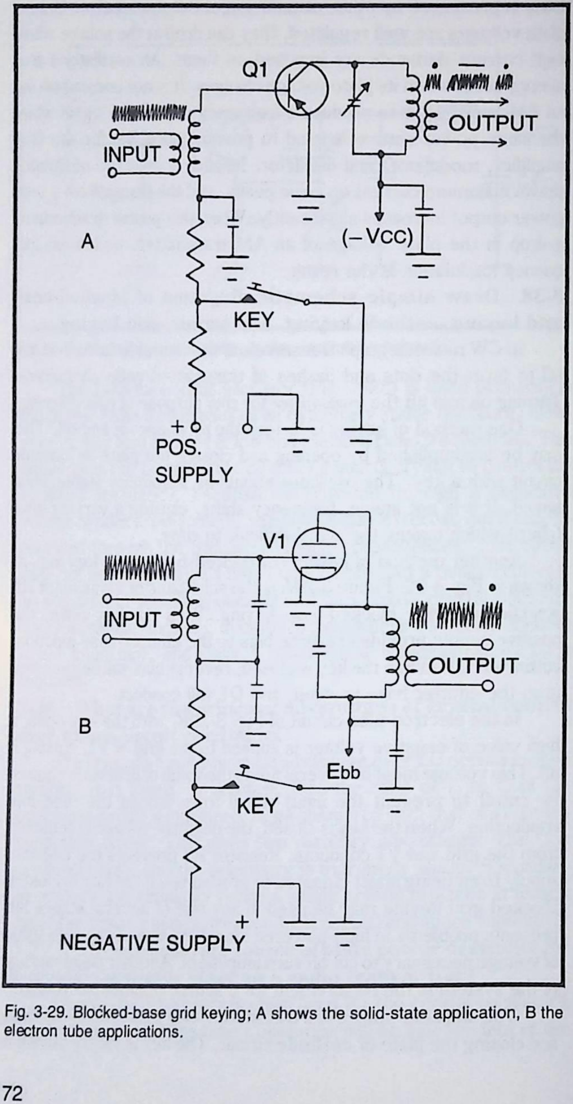


Fig. 3-29. Blocked-base grid keying; A shows the solid-state application, B the electron tube applications.

the plate circuit due to the hazardous DC potentials that would be present across the key. Figure 3-30 shows two methods of keying in the cathode circuit. Figure 3-30A shows center-tap keying of a directly heated cathode or filament, and Fig. 3-30B shows basic cathode keying of an indirectly heated cathode.

In Fig. 3-30A, keying is accomplished by opening and closing the filament transformer center tap line to ground. With the key open the tube is cut off since there is no complete DC path (filament to plate). Capacitors C1 and C2 are RF bypass capacitors. They keep the RF signal out of the filament transformer and the keying line.

In Fig. 3-30B, the key opens and closes the circuit. With the key open, there is no complete DC path (cathode to plate), neither grid nor plate current can flow, and the tube is cut off.

Screen-grid keying is shown in Fig. 3-31. It is a actually a combination of driver stage and final stage keying. In this circuit, a keying relay must be used to prevent operator shock.

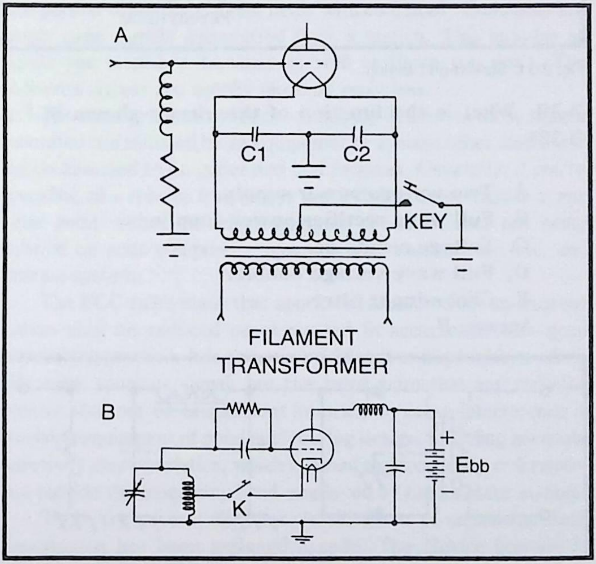


Fig. 3-30. Two methods of keying in the cathode circuit.

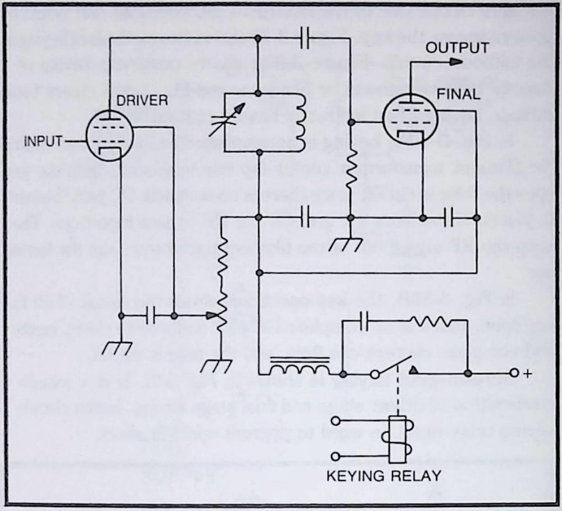


Fig. 3-31. Screen-grid keying.

3-39 What is the function of the circuit shown in Fig. 3-32?

A. Two voltage power supply.
B. Full wave rectifier power supply.
C. Voltage regulator.
D. Full wave voltage doubler.
E. Choke input filter.

Answer: *B*

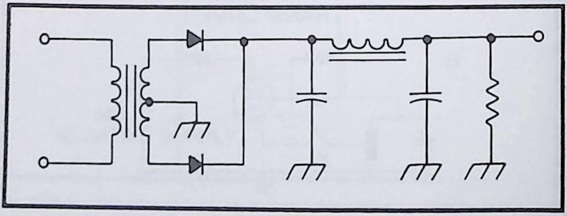


Fig. 3-32. Graphic for Question 3-39.

Chapter 4

Transmitting Signals

One portion of the FCC exam deals with *emissions*. Emissions are simply radio signals transmitted from a station. This includes all signals you intend to transmit as well as those you don't. The undesired signals are usually *spurious emissions*.

The term spurious emissions is usually defined as those signals generated and radiated by an equipment or system other than those signals intended to be generated and radiated. Generally, if you're operating on a specific frequency, there should be no signals at any other point within the electromagnet spectrum that are being radiated by your equipment, power leads, transmission line, and antenna system.

The FCC rules state that spurious radiation from an amateur station shall be reduced or eliminated in accordance with good engineering practice. It is sometimes difficult or impossible to eliminate *every* spurious signal, but the rules state that any radiation present shall not be of sufficient intensity to cause interference in receiving equipment of good engineering design, including adequate selectivity characteristics, which is tuned to a frequency or frequencies outside the frequency band employed by the amateur station.

There are several different classifications of emissions. Each classification has been assigned a code. The Novice licensee is permitted to use only one class of emission—A1. The letter *A* refers

Table 4-1. Emission Codes

EMISSION CODE	DESCRIPTION	TYPE OF MODULATION
A0 F0	On-the-air carrier of an rf transmitter with no modulation	
A1	Telegraphy wihtout the use of a modulating audio frequency (by on-off keying). Referred to as "carrier-keyed telegraphy."	
A2	Telegraphy by on-of keying of an amplitude-modulating audio frequency or audio frequencies, or by the on-off keying of the modulated emission (special case: an unkeyed emission amplitude-modulated).	Amplitude
A3	Radiotelephony	Amplitde
A4	Facsimile	Amplitude
A5	Television	Amplitude
F1	Telegraphy by frequency-shift keying without the use of a modulating audio frequency.	Frequency
F2	Telegraphy by the on-off keying of a frequency-modulating audio frequency or by the on-off keying of a frequency-modulated emission (special case: an unkeyed emission frequency-modulated)	Frequency
F3	Radiotelephony	Frequency
F4	Facsimile	Frequency
F5	Television	Frequency
P	Pulse	

Special Note: In the amateur radio service, A3 also includes single- and double-sideband transmission with full, reduced, or suppressed carrier.

to the type of modulation, which is amplitude, and the *1* refers to the type of transmission, which is telegraph (by on-off keying) without the use of modulating audio frequency. Table 4-1 identifies the different types of emission codes.

The last question in this section is typical of the type of questions to be found on the FCC exam.

4-1 What are spurious emissions?

Spurious emissions are signals generated within the transmitter that are not intended to be processed or radiated by the transmitter circuits. Such emissions, of course, include harmonics; but they also include parasitic oscillations, and signals caused by inadvertent positive feedback in the various stages and by intermodulation.

4-2 What are key clicks?

Theoretically, keying a transmitter should instantly start and stop radiation of the carrier completely. However the sudden application and removal of power creates rapid surges of current which cause interference in nearby receivers. Even though such receivers are tuned to frequencies far removed from that of the transmitter, interference is present in the form of clicks or thumps. To prevent such interference, key click filters are used in the keying systems of

radio transmitters. Two types of key click filters are shown in Fig. 4-1.

The capacitors and RF chokes in both circuits of Fig. 4-1 prevent surges of current. The choke coil, *L*, causes a lag in the current when the key is closed, and the current builds up gradually instead of instantly. Capacitor *C* charges up as the key is opened and slowly releases the energy stored in the inductor magnetic field. Resistor *R* controls the rate of charge and discharge of capacitor *C* and also prevents sparking at the key contacts by the sudden discharge of *C* when the key is closed.

4-3 Define the term "carrier frequency."

To be of practical value the radio signal must carry some type of intelligence. This intelligence is applied to the radio signal at the sending end of the system, and is removed and utilized at the receiving end. In a radio communications system, the signal which carries the intelligence is a high frequency sine wave called a *carrier* wave. The intelligence which is applied to the carrier wave is called *modulation* and can be in the form of a code, voice signals, music, or pictures. When intelligence has been applied to a carrier, the carrier is said to be *modulated*.

4-4 What is the difference between an A0 emission and an A1 emission?

The *A0* emission is a continuous, unmodulated pure carrier signal, while the *A1* emission is continuous-wave (CW) telegraphy by carrier keying.

4-5 What are the standards of good quality in A1 emissions?

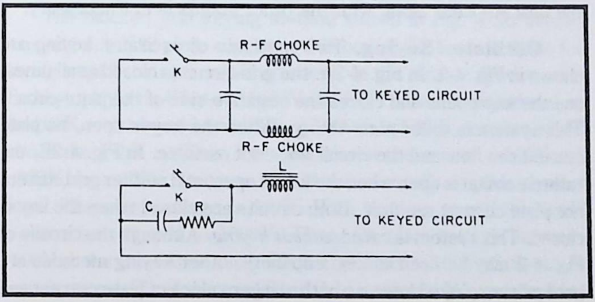


Fig. 4-1. Two types of key click filters.

An *A1* emission should be free from chirps and key clicks. The frequency of the emitted carrier wave should be as constant as the state of the art permits. When the transmitter is not keyed, the output should be zero for the best quality signal to prevent a spacing wave (backwave) between code transmissions.

4-6 What causes a backwave?

A backwave results when some RF energy leaks through to the antenna even though the key is open. The effect is as though the dots and dashes were simply louder portions of a continuous carrier. It may be difficult to distinguish the dots and dashes under such conditions. Backwave radiation is usually the result of incomplete neutralization.

4-7 Describe some of the more common keying methods in CW (A1) transmissions.

Keying a transmitter causes an RF signal to be radiated *only* when the key contacts are closed. When the key is open the transmitter does not radiate energy. Keying is accomplished in either the oscillator or amplifier stages of a transmitter. A number of different keying systems are used in transmitters.

In most transmitters the hand telegraph key is at low potential with respect to ground. The keying bar is usually grounded to protect the operator. Generally a keying relay with its contacts in the center tap lead of the filament transformer is used to key the equipment. Because one or more stages use the same filament transformer, these stages are also keyed. The class *C* final amplifier, when operated with fixed bias, is usually not keyed, because without excitation applied no current flows. Hence, keying the final amplifier along with the other stages is not necessary.

Oscillator Keying. Two methods of oscillator keying are shown in Fig. 4-2. In Fig. 4-2A, the grid circuit is closed at all times, and the key opens and closes the negative side of the plate circuit. This system is called *plate keying.* When the key is open, no plate current can flow and the circuit does not oscillate. In Fig. 4-2B, the cathode circuit is open when the key is open, and neither grid current nor plate current can flow. Both circuits are closed when the key is closed. This system is called *cathode keying.* Although the circuits of Fig. 4-2 may be used to key amplifiers, other keying methods are generally employed because of the larger values of plate current and voltage encountered.

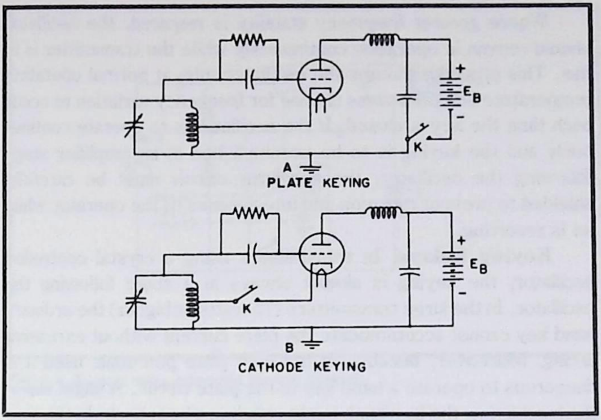


Fig. 4-2. Two methods of oscillator keying.

Blocked Grid Keying. Two methods of blocked grid keying are shown in Fig. 4-3. The key in Fig. 4-3A shorts cathode resistor R_1, allowing normal plate current to flow. With the key open, reduced plate current flows up through resistor R_1, making the end connected to grid resistor R_g negative. If the value of R_1 is high enough, the bias developed is sufficient to cause cutoff of plate current. Depressing the key short circuits R_1, thus increasing the bias above cutoff and allowing the normal flow of plate current. Grid resistor R_g is the usual grid leak resistor for normal bias. This method of keying is applied to the buffer stage in a transmitter.

The blocked grid keying method shown in Fig. 4-3B affords complete cutoff of plate current and is one of the best methods for keying amplifier stages in transmitters. In the voltage divider, with the key open, two-thirds of 1000V, or 667V, are developed across the 200K resistor, and one-third of 1000V, or 333V, are developed across the 100K resistor. The grid bias is the sum of −100V and −333V, or −433V. Because this is below cutoff, no plate current flows. The plate voltage is 667V. With the key closed the 100K resistor is increased to 1000V. Thus, the plate voltage becomes 1000V at the same time the grid bias becomes −100V. Grid bias is now above cutoff and the amplifier triode conducts. Normal amplifier action follows.

Where greater frequency stability is required, the oscillator should remain in operation continuously while the transmitter is in use. This procedure keeps the oscillator tube at normal operating temperature and offers less chance for frequency variation to occur each time the key is closed. If the oscillator is to operate continuously and the keying is to be accomplished in an amplifier stage following the oscillator, the oscillator circuit must be carefully shielded to prevent radiation and interference to the operator while he is receiving.

Keying Relays. In transmitters using a crystal controlled oscillator, the keying is almost always in a stage following the oscillator. In the large transmitters (75 watts or higher) the ordinary hand key cannot accommodate the plate current without excessive arcing. Moreover, because of the high plate potentials used it is dangerous to operate a hand key in the plate circuit. A slight slip of the hand below the key knob might result in a bad shock. In the case of defective RF plate chokes, a severe RF burn might be incurred.

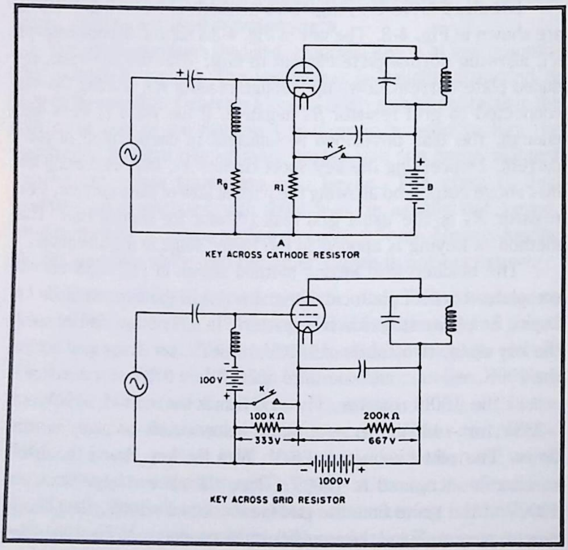


Fig. 4-3. Two methods of blocked-grid keying.

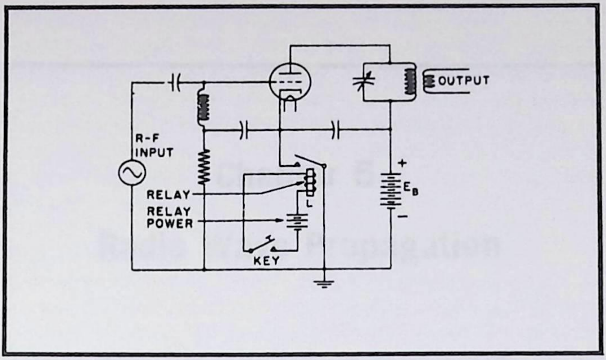


Fig. 4-4. Typical relay-operated keying system.

In these larger transmitters, some local low-voltage supply, such as a battery or the filament supply to the transmitter is used with the hand key to open and close a circuit through the coils of a keying relay. The relay contacts in turn open and close the keying circuits of the amplifier. A schematic diagram of a typical relay-operated keying system is shown in Fig. 4-4. The hand key closes the circuit from the low voltage supply through coil L of the keying relay. The relay armature moves against the tension of a spring. When the hand key is opened, the relay coil is deenergized and the spring opens the relay contacts.

4-8 The symbol A1 designates:

- **A. The purity of an emission.**
- **B. The readability of a signal.**
- **C. The power level of an emission.**
- **D. The stability of an emission.**
- **E. The type of an emission from a radio transmitter.**

Answer: *E*.

4-4. The symbol AI designates:

A. The purity of an emulsion.
B. The [illegible] of a circuit.
C. The power level of an [illegible].
D. The [illegible] of an emulsion.
E. The type of an [illegible].

Answer: A

Fig. 4-3. [illegible]

Chapter 5

Radio Wave Propagation

When a radio wave leaves a vertical antenna, the field pattern of the wave resembles a huge doughnut lying on the ground with the antenna in the hole at the center. Part of the wave moves outward in contact with the ground to form the *ground wave*, and the rest of the wave moves upward and outward to form the *sky wave*. The ground and sky portions of the radio wave are responsible for the two different methods of carrying messages from transmitter to receiver. The ground wave is used both for short-range communications at high frequencies with low power, and for long-range communications at low frequencies with high power. Daytime reception from most nearby commercial stations is carried by the ground wave.

The sky wave is used for long-range, high-frequency daylight communication. At night the sky wave provides a means for long-range contacts at somewhat lower frequencies. It acts somewhat differently than the ground wave. Some of the energy of the sky wave is refracted (bent) by the *ionosphere* so that it comes back toward the earth. A receiver located in the vicinity of the returning sky wave will receive strong signals even though several hundred miles beyond the range of the ground wave.

The ground wave is commonly considered to be made up of three parts—a surface wave, a space wave, and an earth-reflected

wave. The surface wave travels along the earth's surface. The space wave travels in the space immediately above the earth's surface. The earth-reflected wave is reflected from the ground before it reaches the receiver. Since the waves follows paths of different lengths, the components may arrive in or out of phase with each other. Thus as the distance from the transmitter is changed, these components may add or they may cancel. None of these component waves is affected by the reflecting layer of atmosphere high above the surface of the earth called the ionosphere.

The space-wave part of the ground wave becomes more important as the frequency is increased or as the transmitter and receiver antenna height is increased. When the transmitting and receiving antennas are both close to the ground, the space-wave components may cancel. This is true because the ground-reflected component is shifted 180° in phase upon reflection, has the same magnitude as the direct component, and travels a path of approximately the same length as that of the direct component. Thus the surface-wave part of the ground wave is responsible for most daytime broadcast reception.

The ionosphere is found in the rarefied atmosphere approximately 40 to 350 miles above the earth. It differs from the lower atmosphere in that it contains a much higher number of positive and negative ions. The negative ions are believed to be free electrons. The ions are produced by the ultra-violet and particle radiations from the sun. The rotation of the earth on its axis, the annual course of the earth around the sun, and the development of sun spots all affect the number of ions present in the ionosphere, and these in turn affect the quality and distance of radio communications.

At altitudes above 350 miles, the particles of air are too sparse to permit large scale ion formation. Below about 40 miles, only a few ions are present because the rate of recombination is too high. The sun's ultraviolet radiations have been absorbed in their passage through the upper layers of the ionosphere, with the result that below an elevation of 40 miles too few ions exist to materially affect sky wave communication.

The questions in this section pertain to radio wave characteristics and propagation. This includes definitions of various terms associated with radio waves and natural phenomena that affect the transmissions through space from one station to another. Basic data

such as the speed of radio waves, the length of a radio wave vs its frequency, and how daylight affects wave propagation are covered. The last question in the section is a sample question prepared by the FCC.

5-1 What are ground waves? Sky waves?

Primarily, there are two types of transmitted electromagnetic waves, the *ground wave* and the *sky wave*. The ground waves are those that travel near the surface of the earth. These waves are greatly affected by the conductivity of the earth and any obstruction such as mountains or buildings on its surface. Ground-wave transmission is used primarily in local communications.

The ground wave is composed of three waves; the *space* or *tropospheric wave*, the *earth reflected wave*, and the *surface wave*. The space wave is also called the *direct wave*.

The sky wave is an electromagnetic wave which is propagated at such an angle that it travels up through the atmosphere, strikes the upper layer of the atmosphere (called the ionosphere), and is refracted back toward the earth. Sky-wave transmission is used in long-distance transmission.

5-2 What are surface waves?

The *surface wave* is that part of the ground wave which travels in contact with the earth's surface. Because of the conductivity of the earth's surface, some of the energy of the surface wave will be absorbed by the ground. Since the earth's surface in most locations is an excellent conductor, the passing electromagnetic energy will cause eddy currents to flow in the ground. These eddy currents dissipate power and are classified as a loss. Eddy current losses are greatest when the surface wave is polarized horizontally and least

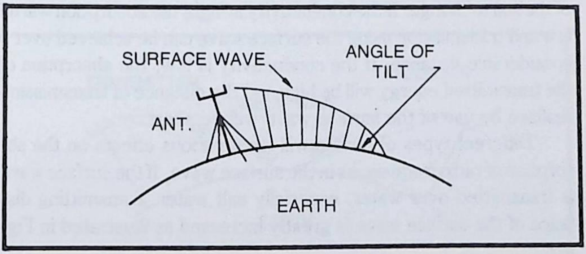


Fig. 5-1. Surface wave characteristics.

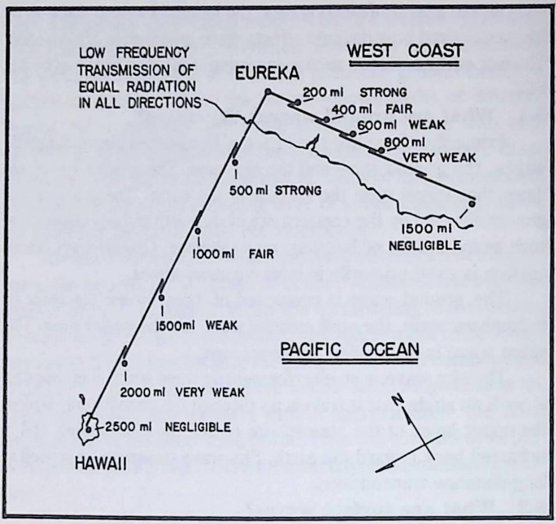


Fig. 5-2. Surface wave transmitting distance is increased over water.

when the surface wave is polarized vertically. The surface wave and the rate at which it diminishes is shown in Fig. 5-1.

Since the electrical properties of the earth along which the surface wave travels are relatively constant, the signal strength from a given station at a given point is fairly constant. This holds true in nearly all localities except those that have a distinct rainy or dry season. Changes in the amount of moisture causes the conductivity of the soil to change. If the conductivity is high, the absorption will be low and transmission using the surface wave can be achieved over a considerable distance. If the conductivity is low, the absorption of the transmitted energy will be high and the distance of transmission realized by use of the surface wave will be short.

Different types of terrain will have various effects on the absorption of radio frequencies in the surface wave. If the surface wave is transmitted over water, especially salt water, transmitting distance of the surface wave is greatly increased as illustrated in Fig. 5-2.

5-3 What are direct (free space) waves?

The *direct* and *earth-reflected waves* are shown in Fig. 5-3. They are also called *free space waves* or *tropospheric waves*. The name tropospheric wave is given since the medium through which the space wave travels is the troposphere, that portion of the atmosphere directly above the earth's surface.

As shown in the diagram, the direct wave is that component of the space wave that travels in almost a straight line from the transmitting antenna to the receiving antenna. This type of transmission, strictly utilizing the direct wave, is known as *line-of-sight transmission*. Line-of-sight transmission means that both the transmitting and receiving antennas are optically visible to one another.

The direct wave travels in almost a straight line, but it is slightly bent by tropospheric *refraction*. This causes the direct wave to be bent back toward the earth, and extends transmission beyond the optical horizon.

Refraction of electromagnetic energy occurs in a manner similar to the refraction of light. Refraction of electromagnetic or light energy is caused when the energy passes from one density medium to another.

5-4 Define skipping and skip distance.

Sky waves are those waves radiated from the transmitting antenna in a direction that produces a large angle with reference to the earth. The sky wave has the ability to strike the ionosphere, be refracted from it to the ground, strike the ground, be reflected back toward the ionosphere, and so forth. The refracting and reflecting action of the ionosphere and the ground is called *skipping*. An illustration of this skipping effect is shown in Fig. 5-4.

The transmitted wave leaves the antenna at point A, is refracted from the ionosphere at point B, is reflected from the ground

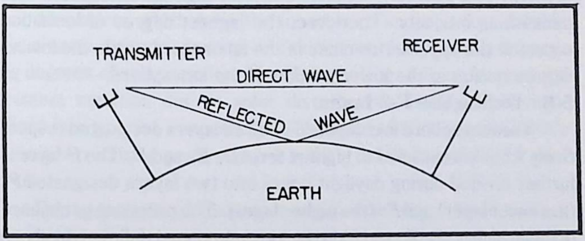


Fig. 5-3. Direct and earth-reflected waves.

at point C, is again refracted from the ionosphere at point D and arrives at the receiving antenna E. The points from A to C, and from C to E indicate a distance that is known as the *skip distance*. The region from the end of the surface wave to point C is known as the *skip* or *quiet zone* because a receiver located within these regions would receive none of the transmitted wave. It is possible, however, that a propagated wave leaving the antenna at a greater angle than the angle shown in Fig. 5-4, would conceivably be refracted into the region. The chance of this happening is small because the angle at which the sky wave strikes the ionosphere is critical. There is another quiet zone between points C and E.

5-5 What is the ionosphere?

As far as electromagnetic radiation is concerned, there are only three layers of the atmosphere. They are the troposphere, the stratosphere, and the *ionosphere*. The troposphere extends from the surface of the earth to an altitude of approximately 6.5 miles. The next layer, the stratosphere, extends from the upper limit of the troposphere to an approximate elevation of 23 miles. From the upper limit of the stratosphere to a distance of approximately 250 miles lies the region known as the ionosphere.

The ionosphere is appropriately titled, because it is composed primarily of ionized particles. The density at the upper extremities of the ionosphere is very low and becomes progressively higher as it extends downward toward the earth. The upper limit of the ionosphere is subjected to severe radiation from the sun. This radiation from the sun is in the form of photons, gamma rays, and other high energy particles. Even though the density of the gases in the upper ionosphere is small, radiation particles from space are of such high energy that they cause wide scale ionization of the gas atoms that are present. This ionization extends down through the ionosphere with diminishing intensity. Therefore, the highest degree of ionization occurs at the upper extremities of the ionosphere, while the lowest degree occurs in the lower portion of the ionosphere.

5-6 Define the F-2 layer.

The ionosphere is composed of three layers designated respectively from lowest level to highest level *D, E,* and *F*. The *F* layer is further divided during daylight hours into two layers designated F_1 (the lower layer) and F_2 (the higher layer). The presence or absence of these layers (D, E, and F) in the ionosphere and their height above the earth vary with the position of the sun.

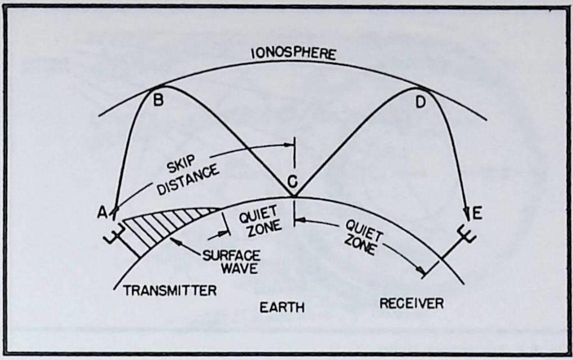


Fig. 5-4. The skip phenomenon.

The *F* layers exist from about 90 to 240 miles. The ionization level in the two *F* layers is quite high and varies widely during the course of a day. At noon, this portion of the atmosphere is closest to the sun and the degree of ionization is maximum. Since the atmosphere is rarefied at these heights, the recombination of the ions occurs slowly after sunset. Therefore, a fairly constant ionized layer is present at all times. The *F* layers are responsible for high frequency long distance transmission.

The relative distribution of the ionospheric layers is shown in Fig. 5-5. With the disappearance of the *D* and *E* layer at night, signals normally refracted by this layer are refracted by the much higher layer, resulting in greater skip distances at night, as shown in Fig. 5-6.

5-7 Define the sunspot cycle.

The layers which form the ionosphere undergo considerable variations in attitude, density, and thickness, due primarily to varying degrees of solar activity. The F_2 layer (Fig. 5-5) undergoes the greatest variation due to solar disturbances (sunspot activity). There is a greater concentration of solar radiation in the earth's atmosphere during peak sunspot activity which recurs in 11 year cycles.

During periods of maximum sunspot activity, the *F* layer is more dense and occurs at a higher altitude, as shown in Fig. 5-7. In Fig. 5-7, conditions are shown for transmitted wavefronts *A* and *B*

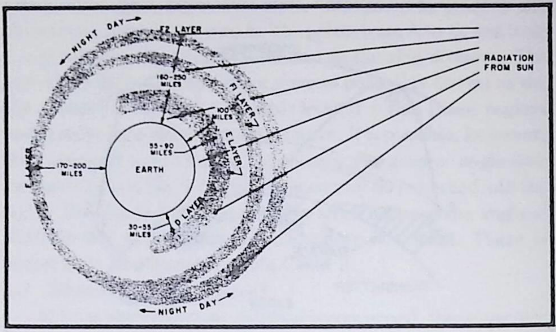


Fig. 5-5. Ionosphere layers.

having different angles of radiation. During periods of minimum sunspot activity, the lower altitude of the *F* layer returns the sky waves (dotted lines) to points relatively close to the transmitter compared with the higher altitude *F* layer occurring during maximum sunspot activity. Consequently, skip distance is affected by the degree of solar disturbance.

5-8 What is a wavelength?

A wavelength is the distance an AC signal, or wave, will travel during one complete cycle. Wavelengths vary with frequency, i.e. a 300 MHz signal has a wavelength of 1 meter (39.37 inches), while a 1 MHz signal has a wavelength of 300 meters.

5-9 What is meant by horizontal and vertical "polarization" of a radio wave?

The radiated energy from an omnidirectional antenna is in the form of an expanding sphere. A small section of this sphere is called a wavefront: it is perpendicular to the direction of travel of the energy. All energy on this surface is in phase. Usually all points on the wavefront are at equal distances from the antenna. The farther from the antenna, the less spherical the wave appears. At a considerable distance the wavefront can be considered as a plane surface at right angles to the direction of propagation.

The radiation field is made up of magnetic and electric lines of force, which are always at right angles to each other. The direction of polarization of most electromagnetic fields is considered to be the direction of the electric vector. That is, if the electric lines of force

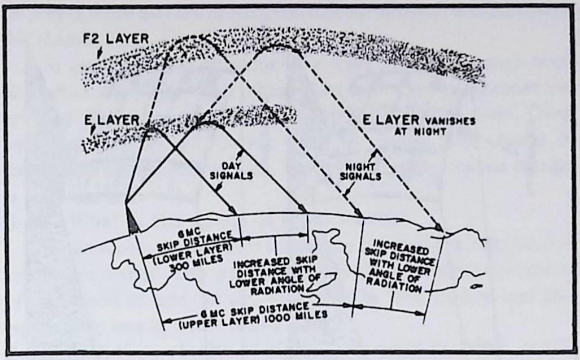


Fig. 5-6. At night, the skip distances become greater.

are horizontal, the wave is said to be horizontally polarized (Fig. 5-8A); and if the electric lines are vertical, the wave is said to be vertically polarized (Fig. 5-8B). As the electric field is parallel to the axis of the antenna (dipole, in this reference), the antenna is in the plane of polarization. The horizontally placed antenna in Fig. 5-8 produces a horizontally polarized wave, and a vertically placed antenna produces a vertically polarized wave.

For maximum absorption of energy from the electromagnetic fields, it is necessary that a receiving dipole be located in the plane of polarization. This places the conductor at right angles to the magne-

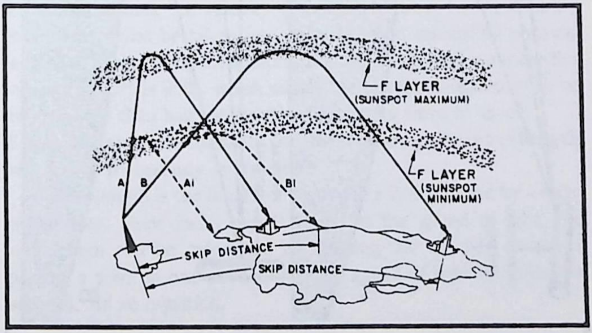


Fig. 5-7. The F layer is denser and higher during maximum sunspot activity.

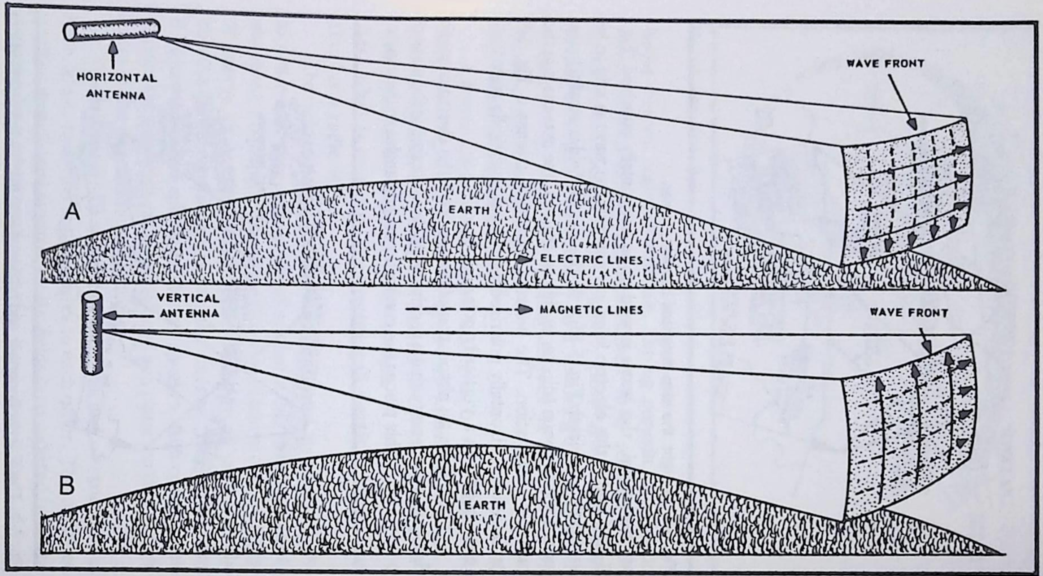


Fig. 5-8. Horizontal (A) and vertical (B) polarization.

tic lines of force that are moving through the antenna, and parallel to the electric lines.

In general, the polarization of a wave does not change over short distances. Therefore, transmitting and receiving antennas are oriented alike, especially if a short distance separates them. Over long distances the polarization tends to change. The change is usually small at low frequencies, but at high frequencies the change is quite marked.

5-10 What is the speed of radio waves?

Radio waves propagate in free space at a speed of 300,000,000 meters per second. This is approximately 186,000 miles per second, or the speed of light. In air, the speed is very slightly less and significantly less in transmission lines.

5-11 Will the velocity of signal propagation differ in different materials? What effect, if any, would this have on wavelength or frequency?

The velocity of propagation differs according to the medium of propagation. Effectively, the result is a change in the electrical length of a wave. The type RG-8/U coaxial cable is a standard transmission line used on many VHF transmitters and receivers. The velocity factor of this cable is approximately 66%; thus, the physical wavelength of a section of this cable is but 66% of the electrical length of an equivalent piece of bare wire hanging in free space, or 66% the length of the tranmsmitted wave in free space. In free space a radio wave propagates at the speed of light, or 300 million meters per second. In air the velocity is very slightly less. In transmission lines the velocity of propagation can be significantly less, and it must be taken into account when calculating physical lengths of RF-carrying conductors. For most half-wave antennas the velocity factory is 95%, which makes the physical length of such an antenna less than half the length of an actual wave in space.

5-12 What is the formula for determining the wavelength when the frequency is known?

Wavelength is the length of a wave in a field emitted by a radio transmitter. Since radio signals travel at the speed of light, the wavelength can be calculated by dividing the number of waves passing a point in one second into the speed of light (in units per second). As an equation,

$$\lambda = \frac{c}{f}$$

where λ is wavelength, c is the speed of light, and f is frequency.

Wavelength generally is expressed in meters, though it could be expressed in centimeters, inches, feet, yards, or miles. For wavelength in meters, the speed of light in meters per second must be used in the formula. Since the speed of light in free space is 300 million (3×10) meters per second (or at least close enough to it so that this number can be used for calculations), the math is greatly simplified. For example, you can divide 300 million by the frequency in hertz, 300,000 by frequency in kilohertz, or 300 by the frequency in megahertz. In other words, you can simplify the problem by the expedient of removing zeros from 300 million, according to the hertz multiplier.

5-13 If the period of one complete cycle of a radio wave is one microsecond (one-millionth of a second), what is the frequency and wavelength?

Since one million such cycles would be propagated in a one-second period, the frequency is one megahertz (1 MHz). The wavelength may be calculated by dividing the velocity of light (velocity of RF propagation) by frequency, or $\lambda = c/f$. The speed of light is 300 million meters per second. Dropping the millions of both speed and frequency, the equation becomes $\lambda = 300/1$, or 300. Thus, the wavelength of a one-megahertz signal is 300 meters.

5-14 What are the effects of the ionosphere on the sky wave?

The ionosphere has many characteristics. Some waves penetrate and pass entirely through it into space, never to return. Other waves penetrate but bend. Generally, the ionosphere acts as a conductor, and absorbs energy in varying amounts from the radio wave. The ionosphere also acts as a radio mirror and refracts (bends) the sky wave back to the earth, as illustrated in Fig. 5-9. Here, the ionosphere does to the sky wave what water does to a beam of light.

The ability of the ionosphere to return a radio wave to the earth depends upon the ion density, frequency of transmission and the angle of radiation. The refractive power of the ionosphere increases with density or degree of ionization. The degree of ionization is greater in summer than in winter, and is also greater during the day than at night. Abnormally high densities occur during times of peak sunspot activity.

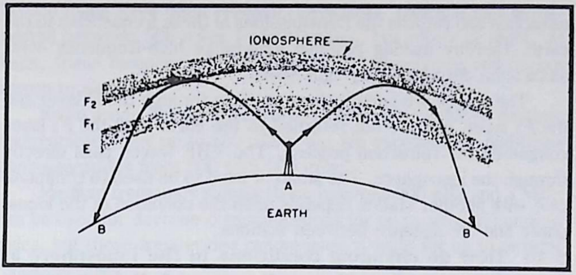


fig. 5-9. Sky wave refraction by the ionosphere.

5-15 What is the effect of daylight on wave propagation?

The increased ionization during the day is responsible for several important changes in sky-wave transmission. It causes the sky wave to be returned to the earth nearer to the point of transmission. The extra ionization increases the absorption of energy from the sky wave; if the wave travels a sufficient distance into the ionosphere, it will lose all of its energy. The presence of the F_1 and E layers with the F_2 layer make long-range, high-frequency communications possible, provided the correct frequencies are used.

Absorption usually reduces the effective daylight communication range of low-frequency and medium-frequency transmitters to surface-wave ranges.

The high degree of ionization of the F_2 layer during the day, enabling refraction of high frequencies which are not greatly absorbed, has an important effect on transmissions of the high-frequency band. Figure 5-10 shows how the F_2 layer completes the

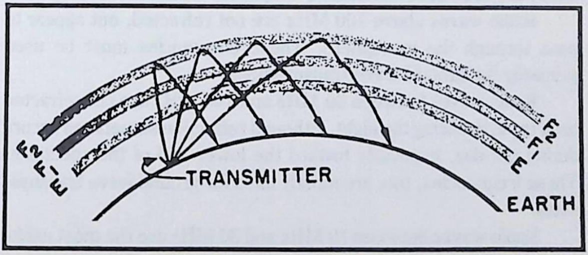


Fig. 5-10. The effect of the F_2 layer on long-range communications.

refraction and returns the transmissions of these frequencies to the earth, thereby making possible long-range high-frequency communication during the day-light hours.

The waves are partially bent in going through the E layer and the F_1 layer, but are not returned to the earth until the F_2 layer completes the refraction process. The VHF waves pass directly through the ionosphere. The amateur band to be used to communicate with another station depends upon the condition of the ionosphere and the distance between stations.

5-16 How do changing conditions in the ionosphere at sunrise and sunset affect radio signals? How do ionospheric storms affect radio signals?

Changing conditions in the ionosphere shortly before sunrise and shortly after sunset may cause complete blackouts at certain frequencies. The higher frequency signals pass through the ionosphere while the lower frequency signals are absorbed by it.

Ionospheric storms (turbulent conditions in the ionosphere) often cause radio communication to become erratic. Some frequencies will be completely blacked out, while others may be reinforced. Sometimes these storms develop in a few minutes, and at other times they require as much as several hours to develop. A storm may last several days.

5-17 How do night and day transmissions differ?

Due to changes in the ionosphere, the sky wave changes between night and day. (The ground wave remains constant, however). The rays of the sun ionize the atmosphere during daylight hours, but as night approaches, the ionized particles become thinner. The thinly ionized layer refracts waves back to the earth over a wider arc than does the thicker "daytime" layer.

Radio waves above 100 MHz are not refracted, but appear to pass through the ionosphere. These frequencies must be used primarily for ground wave transmissions.

Radio waves between 30 MHz and 100 MHz are not refracted back to earth during the night, although refraction sometimes occurs during the day, especially toward the lower end of the spectrum. These frequencies, too, are mostly used for ground wave transmissions.

Radio waves between 10 MHz and 30 MHz are the most useful for long distance daytime communications, and distances up to

10,000 miles have been reached. Ordinarily, contacts can be expected between 500 miles to 5,000 miles, but rarely at night. At night, these frequencies pass through the ionosphere and do not return to earth.

Radio waves between 3 MHz to 10 MHz are useful for daytime communication for up to 500 miles, but are excellent for nighttime communications from 200 to 5,000 miles.

Medium frequency signals those between 300 kHz and 3 MHz can be used for daytime communications for up to several hundred miles, but these frequencies can be used at night for up to several thousand miles.

For frequencies below 3 MHz, there is a little difference between day and night signals, with the stronger signals appearing at night.

5-18 A radiation field contains:

A. Only an electric component.
B. An electric and a magnetic component.
C. Only a magnetic component.
D. A vertically and a horizontally polarized component.
E. None of the above.

Answer: *B*.

Chapter 6
Amateur Radio Operating Procedures

It is a common courtesy to avoid transmitting on a frequency that is currently in use. When tuning up, it is best to use a dummy load, and to always monitor a frequency before transmitting a signal. Amateurs who carelessly interfere with communications because of poor operating practices are frowned upon by the amateur community.

Since amateur bands are crowded, some consideration for other amateurs should be extended. It is not good procedure to "hog" a frequency with a long-winded, one-sided conversation. Short, brief communications will permit maximum use of the frequency, and will also permit an opportunity for another station break in.

If transmitting conditions are poor, or if difficulty is encountered in receiving, it is good practice to delay transmissions until conditions are more favorable.

Station identification should be made clearly and distinctly so that unnecessary repetition of call letters is avoided, and to enable other stations to clearly identify all calls. In order to prevent interference and give others an opportunity to use the amateur bands, avoid unnecessary or "cute" remarks while on the air.

Q Signal System. Over the years, Q signals have been developed. These signals are merely abbreviations of frequently used terms, and have the same meanings internationally. By using

Table 6-1. Commonly Used Q Signals.

Q SIGNAL	QUESTION	ANSWER OR ADVICE
QRA	What is the name of your station?	The name of my station is . . .
QRG	Will you tell me my exact frequency (or that of . . .)?	Your exact frequency (or that of . . .) is . . . kHz (or MHz).
QRH	Does my frequency vary?	Your frequency varies.
QRI	How is the tone of my transmission?	The tone of your transmission is . . .
QRK	What is the readability of my signals (or those of . . .)?	The readability of your signals (or those of . . .) is . . .
QRL	Are you busy?	I am busy (or I am busy with . . .). Please do not interfere.
QRM	Are you being interfered with?	I am being interfered with.
QRN	Are you troubled by static?	I am troubled by static.
QRO	Shall I increase power?	Increase power.
QRP	Shall I decrease power?	Decrease power.
QRQ	Shall I send faster?	Send faster (. . . words per minute).
QRS	Shall I send more slowly?	Send more slowly (. . . words per minute).
QRT	Shall I stop sending?	Stop sending.
QRU	Have you anything for me?	I have nothing for you.
QRW	Shall I inform . . . that you are calling him on . . . kHz (or MHz)?	Please inform . . . that I am calling him on . . . kHz (or MHz).
QRX	When will you call me again?	I will call you again at . . . hours [on . . . kHz (or MHz)].
QRY	What is my turn? (Relates to communication.)	Your turn is No . . . (or according to any other indication). (Relates to communication.)
QRZ	Who is calling me?	You are being called by . . . [on . . . kHz (or MHz)].
QSA	What is the strength of my signals (or those of . . .)?	The strength of your signals (or those of . . .) is . . .
QSB	Are my signals fading?	Your signals are fading.
QSD	Is my keying defective?	Your keying is defective.
QSK	Can you hear me between your signals?	I can hear you between my signals.
QSL	Can you acknowledge receipt?	I am acknowledging receipt.
QSM	Shall I repeat the last communication which I sent you, or some previous communication?	Repeat the last communication which you sent me (or communication number . . .).
QSN	Did you hear me [or . . . (call sign)] on . . . kHz (or MHz)?	I did hear you [or . . . (call sign)] on . . . kHz (or MHz).
QSO	Can you communicate with . . . direct or by relay?	I can communicate with . . . direct (or by relay through . . .).
QSP	Will you relay to . . .?	I will relay to . . .
QSU	Shall I send or replay on this frequency [or on . . . kHz (or MHz)]	Send or reply on this frequency [or . . . kHz (or MHz)]
QSV	Shall I send a series of Vs on this frequency [or . . . kHz (or MHz)]?	Send a series of Vs on this frequency [or . . . kHz (or MHz)].
QSW	Will you send on this frequency [or . . . kHz (or MHz)]	I am going to send on this frequency [or on . . . kHz (or MHz)]
QSX	Will you listen to . . . (call sign) on . . . kHz (or MHz)?	I am listening to . . . (call sign) on . . . kHz (or MHz).

Table 6-1 cont.

Q SIGNAL	QUESTION	ANSWER OR ADVICE
QSY	Shall I change my transmission to another frequency?	Change your transmission to another frequency [or on . . . kHz (or MHz)].
QSZ	Shall I send each word or group more than once?	Send each word or group twice (or . . . times).
QTH	What is your position or location?	My position or location is . . .
QTR	What is the correct time?	The correct time is . . . hours.

these in amateur communications, considerable time is saved because of the brevity and clarity of these signals. You should memorize the meanings of the Q signals so that you can use them in your own transmissions after you receive your Novice license. The FCC exam may have a question or two about Q signals.

Table 6-1 lists the more commonly used Q signals, what each Q signal means as a question, and what each Q signal means as an answer (or advice). It is customary to send a question mark after the Q signal if it is a question.

RST Reporting System. The letters *RST* stand for *readability, signal strength,* and *tone*. Readability is given in numbers 1 through 5 as follows:

1. Unable to read.
2. Can barely copy a few words, most words below noise level.
3. Can copy, but with great trouble.
4. Can copy with almost no trouble.
5. Can copy with no trouble.

Signal strength is given in numbers 1 through 9 as follows:

1. Extremely weak signal.
2. Very weak signal.
3. Weak signal.
4. Fair signal.
5. Reasonably good signal.
6. Good signal.
7. Fairly strong signal.
8. Strong signal.
9. Extremely strong signal.

Tone is reported in numbers 1 through 9 as follows:

1. Up to and including 60 Hz, broad and very harsh sounding.
2. Very rough AC, broad and very harsh.

3. Harsh, unfiltered but rectified AC tone.
4. Rough tone, but has some slight degree of filtering.
5. Filtered and rectified tone, but contains strong ripples.
6. Although filtered, tone has some degree of ripple.
7. Almost pure tone, but has slight degree of ripple.
8. Almost perfect tone except for extremely slight degree of modulation.
9. Pure tone, no degradation whatsoever.

If a tone has clicks or keying transients, the letter *K* is added to the *RST* report, and if chirps are present on either the start or finish of the tone, the letter *C* is added to the report. If both clicks and chirps are present, both *C* and *K* are added.

A reasonably good signal that could be copied with almost no trouble, but with both clicks and chirps in its pure tone, would receive an *RST* report of *459CK*. Note that in the tone report, a pure tone with no degradation whatsoever could still have clicks and chirps. The letter *X* added to the *RST* report indicates a steady tone, characteristic of crystal control, and may appear as *459CX*.
appear as *459CX*.

Standard Abbreviations. In amateur radio work, as in commercial telegraphy, abbreviations have been adopted which mean the same in almost any language. The use of these abbreviations saves time. Table 6-2 lists the more commonly used abbreviations.

Public Service Operations. Many amateur radio clubs, groups, nets, etc. are dedicated to providing their facilities in the interest of public service. In addition to such groups as the Radio Amateur Civil Emergency Service (RACES) and Military Affiliate Radio Service (MARS), literally thousands of amateur operators are organized into service groups.

The Radio Amateur Civil Emergency Service provides for amateur radio operation for civil defense communications purposes only, during periods of local, regional, or national civil emergencies.

To supplement or extend other means of communication available to the civil defense organization or to provide necessary communications for which no other means exist, local radio amateur civil emergency station networks are organized by the civil defense authority of the area concerned and under the immediate direction of the Civil Defense Radio Officer. Such networks include all licensed amateur radio stations which are intended to be included in the civil defense communications plan of the area concerned.

Table 6-2. Standard Abbreviations.

Abbreviation or Signal	Definition
AA	All after . . . (used after a question mark to request a repetition).
AB	All before . . . (used after a question mark to request a repetition).
ABV	Repeat (or I repeat) the figures in abbreviated form.
ADS	Address (used after a question mark to request a repetition).
AR	End of transmission (.-.-. to be sent as one signal).
AS	Waiting period (.-... to be sent as one signal).
BK	Signal used to interrupt a transmission in progress.
BN	All between . . . and . . . (used after a question mark to request a repetition).
BQ	A reply to an RQ.
C	Yes.
CFM	Confirm (or I confirm).
CL	I am closing my staiton.
CP	General call to two or more specified stations.
CQ	General call to all stations.
CS	Call sign (used to request a call sign).
DE	Used to separate the call sign of the station called from the call sign of the calling station.
ER	Here . . .
ETA	Estimated time of arrival.
ITP	The punctuation counts.
JM	Make a series of dashes if I may transmit. Make a series of dots to stop my transmission.
K	Invitation to transmit.
MN	Minutes (or Minutes).
N	No.

Table 6-2 cont.

Abbreviation or Signal	Definition
NIL	I have nothing to send to you.
NW	Now.
OK	We agree (or it is correct).
R	Received.
REF	Reference to . . . (or refer . . .).
RPT	Repeat (or I repeat) (or repeat . . .).
RQ	Indication of a request.
SIG	Signature (used after a question mark to request a repetition).
SOS	Distress signal (......... to be sent as one signal).
TU	Thank you.
TXT	Text (used after a question mark to request a repetition).
VA	End of work (...... to be sent as one signal).
W	Word(s) or [group(s)].
WA	Word after . . . (Use after a question mark to request a repetition).
WB	Word before . . . (used after a question mark to request a repetition).

In any particular area there may be several such networks and each network may be independent of the others. Whenever there is more than one network in the same area, all such networks must share, under a single civil defense communications plan, the available frequencies in an efficient and orderly manner. The various networks in adjacent areas must establish proper liaison, and a description of the arrangements made shall become a part of their respective civil defense communications plans. Such arrangements provide for the efficient sharing of frequencies, plans for operating procedure designed to avoid mutual interference, and the exchange of communications facilities upon an interarea basis where need for such exchange may arise.

An authorization to operate a station in the Radio Amateur Civil Emergency Service will be issued only to a person who holds an amateur radio operator license, other than Technician or Novice class, and an appropriate amateur radio station license. However, Novice class operators can still be of service, as provided in the Commission's rules and regulations. Any station in the Radio Amateur Civil Emergency Service may be operated by any class of amateur radio operator license issued by the Commission with certain provisions. When the operation of the station is performed by the holder of a Novice class amateur operator license, (1) such operator shall be prohibited from making any adjustments that may result in improper transmitter operation. (2) the equipment shall be so designed and installed that none of the operations necessary to be performed during the course of the normal rendition of the service of the station may cause off-frequency operation or result in any unauthorized radiation, and (3) any needed adjustments of the transmitter that may affect the proper operation of the station shall be regularly made by or under the immediate supervision and responsibility of the holder of either an amateur operator license other than the Novice class or a commercial radiotelephone or radiotelegraph first- or second-class operator license.

Amateur radio operators interested in this area of public service should contact the local civil defense authority.

Message Traffic. A public service area where there is a great deal of activity is in third-party message handling. A friend or acquaintance, or another amateur, may request your help in message traffic. It is the responsibility of any operator who accepts traffic of any kind to relay it as soon as possible, generally within 24 hours, but not later than 48 hours.

The best way to relay a message might be through an organized net, especially for those unfamiliar with third-party message traffic. A net is merely an organization of amateur radio operators, with each net operating by its own set of rules. At some prescribed time (usually 7:00 p.m. daily), the individual operators check in over the air with net control (an amateur operator assigned that task) who more or less "chairs" the activities.

Message nets are located in sections, and sections in regions. A section may cover an entire state, and a region an entire calling area. A section representative will transmit and receive traffic through a

region representative, who in turn operates as a relay center through an area net. Area nets usually cover a time zone.

Traffic then filters back down to the section nets, where it is transmitted to the addressee.

Any amateur operator, regardless of the class of his license, can provide a public service in one of these nets.

6-1 The Q signal "QRM" generally means,

A. A transmission is experiencing interference.

B. A frequency is varying.

C. A reply is requested on a certain frequency.

D. The sending speed is too fast.

E. The previous message is to be repeated.

Answer: *A*.

6-2 What is the Radio Amateur Civil Emergency Service?

The Radio Amateur Civil Emergency Service is a radiocommunication service that is carried on by licensed amateur radio stations. These stations operate on specifically designated segments of the regularly allocated amateur frequency bands under the direction of authorized local, regional, or federal civil defense officials pursuant to an approved civil defense communications plan.

6-3 What is a Radio Amateur Civil Emergency Station?

A radio amateur civil emergency station is an amateur radio station which is authorized to operate in the Radio Amateur Civil Emergency Service for the purpose of transmitting and receiving civil defense communications.

Chapter 7

Rules & Regulations

The questons in this section generally apply to all segments of amateur radio, and are designed to give the novice the basic knowledge and scope of the FCC rules and regulations. Any of these questions may appear on the Novice exam. The last question in the section is a sample question prepared by the FCC.

7-1 What is the basis and purpose of the Federal Communications Commission's rules and regulations?

The rules and regulations are designed to provide an amateur radio service having a fundamental purpose as expressed in the following principles:

1. Recognition and enhancement of the value of the amateur service to the public as a voluntary noncommercial communication service, particularly with respect to providing emergency communications.
2. Continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art.
3. Encouragement and improvement of the amateur radio service through rules which provide for advancing skills in both the communication and technical phases of the art.
4. Expansion of the existing reservoir within the amateur radio service of trained operators, technicians, and electronics experts.

5. Continuation and extension of the amateur's unique ability to enhance international good will.

7-2 Define the term amateur radio service.

Amateur radio service is a radio communication service of self-training, intercommunication, and technicial investigation carried on by amateur radio operators.

7-3 Define the term amateur radio operator.

An amateur radio operator is a person interested in radio technique solely with a personal aim and without pecuniary interest, holding a valid Federal Communications Commission license to operate amateur radio stations.

7-4 Define the term amateur radio station.

An amateur radio station is a station licensed in the amateur radio service embracing necessary apparatus at a particular location used for amateur radio communication.

7-5 Define the term control station.

A control station is a station licensed to conduct remote control of another amateur radio station.

7-6 Define the term station license.

A station license is the instrument of authorization from the Federal Communications Commission for a radio station in the amateur radio service.

7-7 What is the "primary station"?

The primary station is the principal amateur radio station at a specific land location shown on the station license.

7-8 How is effective radiated power calculated?

Effective radiated power is the product of the radio-frequency power, expressed in watts, delivered to an antenna, and the relative gain of the antenna over that of a half-wave dipole antenna.

7-9 What are the frequency and emission privileges autorized to Novice class licensees?

Radiotelegraphy is authorized in the frequency bands 3700–3750 kHz, 7100–7150 kHz (7050–7075 kHz when the terrestrial location of the station is not within Region 2), 21,100–21,200 kHz, and 28,100–28,200 kHz, using only type A1 emission.

7-10 For how long is a Novice class license valid? May it be renewed?

The Novice class license is normally valid for a period of five years from the date of issuance. It can be renewed.

7-11 Why are height limitations placed on amateur radio antenna structures?

Unreasonable heights of antenna structures may adversely affect safety in air navigation.

7-12 What are the responsibilities of the station licensee?

The licensee of an amateur station is responsible for its proper operation. In addition to conforming to the Commission's rules and regulations, each amateur station must be operated in accordance with good engineering and good amateur practice.

7-13 May an amateur station licensee permit a third party to participate in radio communication from his station?

The licensee of an amateur radio station may permit any third party to participate in amateur radio communication from his station, provided that a control operator is present and continuously monitors and supervises the radio communication to insure compliance with the rules.

7-14 What is the primary responsibility of the control operator?

Every amateur radio station, when in operation, shall have a control operator at an authorized control point. The control operator shall be on duty, except where the station is operated under automatic control. The control operator may be another amateur radio operator with the required class of license and designated by the station licensee. The control operator shall also be responsible, together with the station licensee, for the proper operation of the station.

7-15 During operation, when should the amateur station's call sign be transmitted?

An amateur station shall be identified by the transmission of its call sign at the beginning and end of each single transmission or exchange of transmissions, and at intervals not to exceed 10 minutes during any single transmission or exchange of transmissions of more than 10 minutes duration. Additionally, at the end of an exchange of telegraphy (other than teleprinter) or telephony transmissions between amateur stations, the call sign (or the generally accepted network identifier) shall be given for the station, or for at least one of the group of stations, with which communication was established.

7-16 Under what conditions, if any, are one-way communications authorized?

Amateur stations may be used for transmitting signals, or communications, or energy, to receiving apparatus for the measurement of emissions, temporary observation of transmission phenomena, radio control of remote objects, and similar experimental purposes.

In addition to the experimental one-way transmission, the following kinds of one-way communications, addressed to amateur stations, are authorized and will not be construed as broadcasting: (a) emergency communications, including bonafide emergency drill practice transmissions; (b) information bulletins consisting solely of subject matter having direct interest to the amateur radio service as such; (c) round-table discussions or net-type operations where more than two amateur stations are in communication, each station taking a turn at transmitting to other stations of the group; and (d) code practice transmissions intended for persons learning or improving proficiency in the international Morse code.

7-17 Discuss the rules regarding the availability (for purposes of inspection) of the station license at the transmitting station.

The original license of each amateur station (or a photocopy thereof) shall either be posted in a conspicuous place in the room occupied by the licensed operator, or kept in his personal possession, while the station is being operated at a fixed location. When the station is operated at other than a fixed location, the original station license (or a photocopy thereof) shall be kept in the personal possession of the station licensee (or a licensed representative) who shall be present at the station while it is being operated as a portable or mobile station.

The original station license shall be available for inspection by any authorized Government official at all times while the station is being operated, and at other times upon request made by an authorized representative of the Commission, except when such license has been filled with application for modification or renewal thereof, or has been mutilated, lost, or destroyed, and request has been made for a duplicate.

Any licensee requesting a duplicate license to replace an original which has been lost, mutilated, or destroyed, shall submit a statement setting forth the facts regarding the manner in which the original license was lost, mutilated, or destroyed. If, subsequent to

receipt by the licensee of the duplicate license, the original license is found, either the duplicate or the original license shall be returned immediately to the Commission.

7-18 Discuss the rules regarding the availability (for purposes of inspection) of the operator license.

The original operator license of each operator shall be kept in the personal possession of the operator while he is operating an amateur station. When operating an amateur station at a fixed location, however, the license may be posted in a conspicuous place in the room occupied by the operator.

The license shall be available for inspection by an authorized Government official whenever the operator is operating an amateur station and at other times upon request made by an authorized Government official whenever the operator is operating an amateur station and at other times upon request made by an authorized representative of the Commission, except when such license has been filed with application for modification or renewal thereof, or has been mutilated, lost or destroyed, and request has been made for a duplicate license. The Government will not accept a photocopy of an operator license, but you are not prohibited from photocopying your amateur radio operator license.

7-19 Describe the station log requirements. How long must station logs be retained?

An accurate legible account of station operation shall be entered into a log for each amateur radio station. Except for remotely controlled stations (to which additional rules apply), the following items shall be entered as a minimum:

1. The call sign of the station, the signature of the station licensee, or a photocopy of the station license.
2. The locations and dates upon which fixed operation of the station was initiated and terminated. If applicable, the location and dates upon which portable operation was initiated and terminated at each location.
3. The date and time periods in which the duty-control operator for the station was other than the station licensee, and the signature and primary station call sign of that duty-control operator.
4. A notation of third-party traffic sent or received, including names of all third parties, and a brief description of the

traffic content. This entry may be in a form other than written, but one which can be readily transcribed by the licensee into written form.

5. Upon direction of the commission, additional information as directed shall be recorded in the station log.

The station log shall be preserved for a period of at least 1 year following the last date of entry and retained in the possession of the licensee.

7-20 Discuss the rules regarding frequency measurement.

The licensee of an amateur station shall provide for measurement of the emitted carrier frequency or frequencies and shall establish procedure for making such measurement regularly. The measurement of the emitted carrier frequency or frequencies shall be made by means independent of the means used to control the radio frequency or frequencies generated by the transmitting apparatus and shall be of sufficient accuracy to assure operation within the amateur frequency band used.

7-21 Name three types of stations with which amateur stations may establish communications.

Amateur stations may communicate with:

1. Other amateur stations, except those amateur stations located in certain countries whose governments object to such radio communications. (These countries are listed in public notices issued by the Commission.)
2. Stations in other services licensed by the Commission, and with U. S. Government stations for civil defense purposes (Radio Amateur Civil Emergency Service RACES) in emergencies, and on a temporary basis for test purposes.
3. Any station which is authorized by the Commission to communicate with amateur stations.

7-22 Under what circumstances may the Commission impose administrative sanctions against an amateur station? What are these sanctions?

If the operation of an amateur station causes general interference to the reception of transmissions from stations operating in the domestic broadcast service when receivers of good engineering design including adequate selectivity characteristics are used to

receive such transmissions, and this fact is made known to the amateur station licensee, the amateur station shall not be operated during the hours from 8:00 p.m. to 10:30 p.m., local time, and on Sunday for the additional period from 10:30 a.m. until 1:00 p.m. local time, upon the frequency or frequencies used when the interference is created.

In general, such other steps as may be necessary to minimize interference to stations operating in other services may be required after investigation by the Commission.

In every case where an amateur station licensee is cited within a period of 12 consecutive months for the second violation of any of the provisions covering: (a) authorized frequencies and emissions, (b) sideband frequencies out of band, (c) emission limitations, (d) filtering of transmitter plate supply, or (e) purity and stability of emissions, the station licensee, if directed to do so by the Commission, shall not operate the station and shall not permit it to be operated from 6:00 p.m. to 10:30 p.m. local time, until written notice has been received authorizing the resumption of full-time operation. This notice will not be issued until the licensee has reported on the results of tests which he has conducted with at least two other amateur stations at hours other than 6:00 p.m. to 10:30 p.m. local time. Such tests are to be made for the specific purpose of aiding the licensee in determining whether the emissions of the station are in accordance with the Commission's rules. The licensee shall report to the Commission the observations made by the cooperating amateur licensees in relation to the reported violations. This report shall include a statement as to the corrective measures taken to insure compliance with the rules.

In every case where an amateur station licensee is cited within a period of 12 consecutive months for the third offense of the violations described in the previous paragraph the station licensee, if directed by the Commission, shall not operate the station and shall not permit it to be operated from 8:00 a.m. to 12:00 midnight, local time, except for the purposes of transmitting a prearranged test observed by a monitoring station of the Commission to be designated in each particular case. The station shall not be permitted to resume operation during these hours until the licensee is authorized by the Commission, following the test, to resume full-time operation. The results of the test and the licensee's record shall be

considered in determining the advisability of suspending the operator license or revoking the station license, or both.

7-23 What is required of a licensee if he receives an official notice of violation from the Commission?

Any licensee receiving official notice of a violation of the terms of the Communications Act of 1934, as amended, any legislative act, Executive order, treaty to which the United States is a party, or the rules and regulations of the Federal Communications Commission, shall, within 10 days from such receipt, send a written answer direct to the office of the Commission originating the official notice, *provided, however*, that if an answer cannot be sent or an acknowledgement made within such 10-day period by reason of illness or other unavoidable circumstances, acknowledgement and answer shall be made at the earliest practicable date with a satisfactory explanation of the delay.

The answer to each notice shall be complete in itself and shall not be abbreviated by reference to other communications or answers to other notices. If the notice relates to some violation that may be due to the physical or electrical characteristics of transmitting apparatus, the answer shall state fully what steps, if any, are taken to prevent future violations, and if any new apparatus is to be installed, the date such apparatus was ordered, the name of the manufacturer, and promised date of delivery. If the notice of violation relates to some lack of attention or improper operation of the transmitter, the name of the operator in charge shall be given.

7-24 Can an amateur station engage in any form of broadcasting?

Subject to the provisions covering emergency communications, amateur radio bulletins, round table discussions, net-type operations, and code practice transmissions, an amateur station shall not be used to engage in any form of broadcasting, i.e. the dissemination of radio communications intended to be received by the public directly or by the intermediary of relay stations, nor for the retransmission by automatic means of programs or by the intermediary of relay stations, nor for the retransmission by automatic means of programs or signals emanating from any class of station other than amateur. The foregoing provisions shall not be construed to prohibit amateur operators from giving their consent to the rebroadcast by

broadcast stations of the transmissions of their amateur station, provided that the transmissions of the amateur stations shall not contain any direct or indirect reference to the rebroadcast.

7-25 Is it permissible to key (turn on) a transmitter for short test periods (less than one minute) without identifying the transmitting station?

No licensed radio operator shall transmit unidentified radio communications or signals.

7-26 What are the rules regarding prohibited third-party traffic?

The transmission or delivery of the following amateur radiocommunication is prohibited:

1. International third party traffic except with countries which have assented thereto;
2. Third party traffic involving material compensation, either tangible or intangible, direct or indirect, to a third party, a station licensee, a control operator, or any other person.
3. Except for an emergency communication, third party traffic consisting of business communications on behalf of any party. For this purpose, business communication shall mean any transmission or communication the purpose of which is to facilitate the regular business or commercial affairs of any party.

7-27 What transmissions and practices by amateur licensees are prohibited?

Prohibited transmissions and practices are:

1. Transmitting or receiving messages for hire.
2. Broadcasting.
3. Transmitting certain third party traffic (see question 7-26 above).
4. Transmitting music.
5. Transmitting for unlawful purposes.
6. Transmitting messages in secret codes or ciphers.
7. Transmitting words of obscenity, indecency, or profanity.
8. Transmitting false or deceptive signals.
9. Transmitting unidentified communications.
10. Willfully interfering with any radio communication or signal.

11. Willfully damaging radio apparatus or installation in any licensed radio station.
12. Obtaining or providing assistance in the obtaining, of an operator license by fraudulent means.
13. Retransmitting radio signals.

7-28 Who is eligible for the Novice class amateur operator license?

Anyone except a representative of a foreign government. The Novice class license is not renewable.

7-29 What are the general eligibility requirements for an amateur station license?

An amateur radio station license will be issued only to a licensed amateur radio operator, except that a military recreation station license may also be issued to an individual not licensed as an amateur radio operator (other than a representative of a foreign government), who is in charge of a proposed military recreation station not operated by the U. S. Government but which is to be located in approved public quarters.

7-30 Under what conditions may the Commission modify a station license?

Whenever the Commission shall determine that public interest, convenience, and necessity would be served, or any treaty ratified by the United States will be more fully complied with, by the modification of any radio station license, either for a limited time or for the duration of the term thereof, it shall issue an order for such licensee to show cause why such license should not be modified.

Such order to show cause shall contain a statement of the grounds and reasons for such proposed modification, and shall specify wherein the said license is required to be modified. It shall require the licensee against whom it is directed to appear at a place and time therein named, in no event to be less than 30 days from the date of receipt of the order, to show cause why the proposed modification should not be made and the order of modification issued.

If the licensee against whom the order to show cause is directed does not appear at the time and place provided in said order, a final order of modification shall issue forthwith.

7-31 Which one of the following is not included in the log of an amateur radio station?

A. The call sign of the station being called.
B. The manufacturer of the equipment being used.
C. The signature of each control operator.
D. The type of emission used.
E. The message traffic handled.

Answer: *B*.

[illegible]
B. The [illegible]
C. The [illegible]
[illegible]

[illegible]

Which one of the following is not included in the list of [illegible]

[illegible]

Part II
The General and Technician Classes

The same study questions are used for the General and Technician class licenses. The General class license provides all amateur privileges except those reserved for the Advanced and Extra class licensees. The General class examination consists of a 13 word-per-minute code test, and the Technician a 5 word-per-minute code test. Both classes require a written examination on basic FCC rules, and general amateur practice and regulations.

The Technician class license is offered to those interested in the VHF, UHF, and higher frequencies. Anyone except a representative of a foreign government is eligible to apply for this class of license.

The written test covers general amateur practice and regulations involving station operation and apparatus, and provisions of treaties, statutes, and rules affecting amateur stations and operators. The FCC exam covers eight sections: (1) rules and regulations, (2) radio phenomena, (3) operating procedures, (4) emission characteristics, (5) electrical principles, (6) practical circuits, (7) circuit components, (8) antennas and transmission lines, and (9) radio communication practices.

In addition to the questions in this part, you should also be familiar with the subject matter given in Part I of this book, the Novice class study questions. Some of those questions may appear on the General class exam.

Part II

The General and Technician Classes

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Chapter 8
Electrical Principles

The terms used in electronics soon become second nature to use if we use them often enough. In this section, we will reveiw the basic terms used in electronics and the fundamental relationships in circuit theory. To the experienced electronic technician, this section may seem elementary, but to newcomers, many strange terms may appear.

You are sure to receive questions regarding the data found here on your FCC examination. Make sure your understand all the definitions and principles given.

8-1 Define the term impedance.

Impedance is the term given to an AC circuit that usually contains both reactance and resistance. It is measured in ohms, and symbolized by the letter Z. Impedance is thus the AC equivalent of DC resistance.

8-2 What is reactance?

Reactance has been classified into two primary categories—inductive reactance and capacitive reactance. Inductive reactance is the opposition that an inductance offers to a changing *current*. A coil reacts to a current change by generating a counter emf, which opposes the change in current. Capacitive reactance, on the other hand, is the opposition that a capacitance offers to a changing *voltage*.

The opposition that an inductance offers to a changing current is called self-induced voltage, or CEMF, and is measured in volts. However, opposition to current flow is normally measured in ohms,

not in volts. Since a coil reacts to a current change by generating a CEMF, a coil is said to be reactive. The opposition of a coil is therefore called reactance (X) and is measured in ohms. Since more than one kind of reactance exists, the subscript L is added to denote inductive reactance. Thus, the opposition offered by a coil to alternating current, termed inductive reactance, is designated by X_L.

The definition of capacitance is the ability to oppose a change in applied voltage. When the applied voltage is changed the capacitor charges or discharges until the voltage on the capacitor is equal to the new value of applied voltage. When the capacitor voltage is equal to the source voltage, no more current flows. Since a capacitor reacts to a voltage change by producing a CEMF, a capacitor is said to be reactive. The opposition to change by a capacitor is also called reactance (X) and is also measured in ohms. In order to distinguish capacitive reactance from inductive reactance (X_L), the subscript C is added to the symbol X. The opposition offered by a capacitor to alternating current is termed capacitive reactance and designated by X_C.

In an inductive circuit, the current lags the applied voltage by 90°, while in a capacitive circuit the current leads the voltage by 90°.

8-3 Explain the term decibel.

The decibel is a linear means of expressing logarithmic changes in power or level. The international transmission unit is the bel, which is equal to 10 decibels. So the first definition of the decibel is "one-tenth of a bel." The bel is itself equivalent to a 10:1 ratio of power, so the gain in bels is the number of times that 10 is taken as a factor to equal the ratio of output power (of an amplifier or any other device) to the input power.

There are some convenient rules of thumb, but if you use them you have to remember what you're measuring. Voltage changes bring about current changes that, in turn, increase power levels, which are themselves the elements actually being compared in decibel values. Doubling any power is the same as increasing the power by 3 decibels (dB). Halving any power value is the same as decreasing the power by 3 dB. Doubling of either voltage or current, though, results in a 6 dB increase—because doubling of voltage forces a doubling of current as well, resulting in a quadrupling of power.

Each time a power value is increased by an order of magnitude (factor of 10) the gain is increased by 10 dB. The basic ratios are as follows:

Power Ratio	No. of 10 Factors	No. of Bels	No. of dB
1,000,000 to 1	6	6	60
100,000 to 1	5	5	50
10,000 to 1	4	4	40
1,000 to 1	3	3	30
100 to 1	2	2	20
10 to 1	1	1	10
1 to 1	0	0	0

8-4 What is the effective value of a sine wave in relation to its peak value?

The effective value is more commonly referred to as the *rms value*. The (effective) value of a sinusoidal voltage or current is 0.707 times the peak value, or equal to the peak (or maximum) value divided by the square root of 2 (1.414). The average, effective, and maximum values of a sine wave are shown graphically in Fig. 8-1.

8-5 Define the following and describe a practical situation in which each might be used:

- **Rms voltage**
- **Peak current**
- **Average current**
- **Power**
- **Energy**

RMS Voltage. The term rms means *root mean square* and is applied to alternating voltages as a means of comparison with an

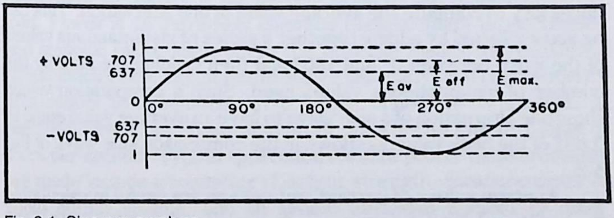


Fig. 8-1. Sine wave values.

equivalent DC voltage value. In AC, rms is the voltage required to deliver the same effective power to a load as a DC source. As the use of AC gained popularity, it became increasingly apparent that some common basis was needed on which AC and DC could be compared. A 100W light bulb, for example, should work just as well on 120V AC as it does on 120V DC. However, a sine wave of voltage having a peak value of 120V would not supply the lamp with as much power as a steady source of 120V DC.

Since the power dissipated by the lamp is a result of current through the lamp, the problem resolves to one of finding a mean alternating-current ampere that is equivalent to a steady ampere of direct current. Figure 8-2 shows a comparison between the various values that are used to indicate the value of a sine wave of voltage. As shown, the effective, or rms, value of the wave—which is the DC equivalent—is 70% (0.707) of the peak value.

Peak Current. One of the most frequently measured characteristics of a sine wave is its amplitude. The amount of alternating current or voltage present in a circuit can be measured in various ways. In one method the maximum amplitude of either the positive or negative alternation is measured. The value of current or voltage obtained is called the peak voltage or current. To measure the peak value of current or voltage, an oscilloscope or special meter (peak reading) must be used. The peak value of a sine wave is illustrated in Fig. 8-2; notice that the value is 100 when the average value is 63.7 and the rms value is 70.7.

Measurements of peak current are often made on antennas, transmission lines, audio circuits, and rf amplifiers.

Average Current. The average value of a complete cycle of a sine wave is zero, since the positive alternation is identical to the negative alternation. In certain types of circuits, however, it is necessary to compute the average value of one alternation. This can be accomplished by adding together a series of instantaneous values of the wave between 0° and 180° and then dividing the sum by the number of instantaneous values used. Such a computation would show one alternation of a sine wave to have an average value equal to 0.637 of the peak value, as shown in the comparison sine wave of Fig. 8-2.

Average values of current and voltage are useful in calculating the unfiltered output voltages and currents of rectifiers. The DC

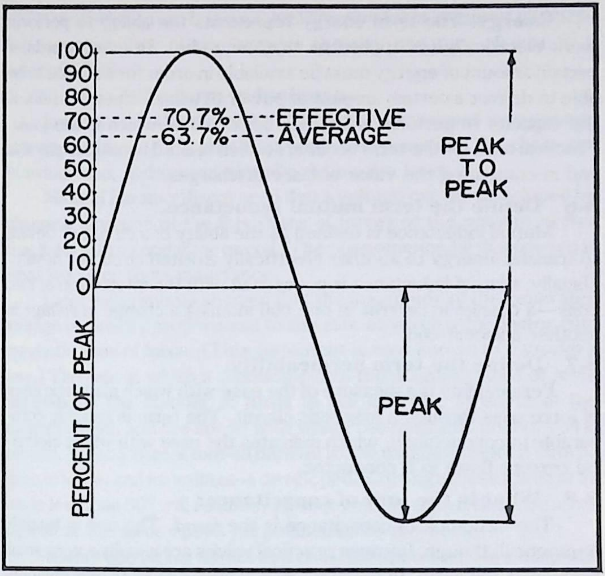


Fig. 8-2. Comparison sine wave.

output of an unfiltered rectifier is equal to the average value of the applied voltage alternations.

Power. A value of power is a means for measuring the rate at which work is accomplished, and it may be calculated in purely resistive circuits by multiplying a load's current by its source voltage. If the source voltage is unknown, power may be calculated by multiplying the square of the current drain by the resistance of the load. Power is an extremely common measurement in electronics and amateur radio, for it offers the principal means for measuring circuit efficiencies, circuit performance capability, and requirements of a source to adequately drive a load. The watt is the unit of electrical power, and is equal to work done at the rate of 1 joule of work per second. Typical applications where power measurements are made include transmitter rf output strength, measurements of audio output volume, and an almost unlimited number of other functions, both AC and DC.

Energy. The term energy represents the ability to perform work electrically (as applied to amateur radio). In other words, a certain amount of energy must be available in order for a source to be able to deliver a certain amount of power to a load. Energy, then, is the capacity to perform work, the basic unit of which is the joule. Practical uses for the term occur in studies related to nuclear physics and in computing the value of laser discharges.

8-6 Define the term mutual inductance.

Mutual inductance is defined as the ability of a circuit or device to transfer energy to another electrically isolated circuit or device. Usually, mutual inductance is concerned with the interaction of two coils—a change in *current* in one coil induces a change in *voltage* in another adjacent coil.

8-7 Define the term permeability.

Permeability is a measure of the ease with which magnetic lines of force pass through a magnetic circuit. The term is roughly comparable to conductance, which indicates the ease with which electrical current flows in a conductor.

8-8 What is the unit of capacitance?

The basic unit of capacitance is the *farad*. The unit is terribly impractical, though, because practical values are usually a very small fraction of one farad. In practice, microfarads (equal to one-millionth of a farad) and picofarads (equal to one trillionth of a farad) are quite common, though the nanofarad (one billionth of a farad) is also in common use.

8-9 What is the unit of inductance?

The basic unit of inductance is the henry. While the henry is not as unwieldy as the farad, the subunits are still a little more common, particularly at radio frequencies. The subunits are the millihenry, microhenry, and nanohenry.

8-10 What is the meaning of power factor?

Power factor is the *cosine of the phase angle between voltage and current* in a circuit, and is usually expressed as a decimal fraction or a percentage. Since power calculations using Ohm's law do not take reactance into account, power calculations on AC circuits result in an "apparent" power, which must be corrected for by multiplying apparent power by the power factor.

8-11 What is meant by ampere-turns?

One ampere-turn is the magnetomotive force required to establish a current flow of one ampere through one turn of wire in a magnetic field.

8-12 Define the term inductance.

Inductance is the property of a circuit that causes it to oppose change in current through it. But while this describes the character of inductance, it does not actually define the term.

Michael Faraday discovered that a voltage may be developed by changing direction of the flux (lines of force) or the amount of flux that links with a conductor or coil. The phenomenon he discovered is what we refer to as inductance.

Later experiments showed that the magnitude of the generated voltage is directly proportional to the rate at which a conductor cuts magnetic lines of force. (This statement is now known as *Faraday's law*.) The rate at which a conductor cuts the magnetic lines of force depends on the number of turns in the coil, the strength of the magnetic field, and the speed with which the magnetic field or coil is moved. When a wire is moved parallel to the magnetic field, it cuts no lines of force, and no voltage is developed. Cutting across a field at an angle less than 90° will result in a lower voltage than if the wire were moved at the same speed perpendicular to the field.

When a conductor moves at a constant speed across a magnetic field of uniform flux density, one volt is generated for every 100 million lines cut per second. The amount of emf generated this way can be put in the form of a formula:

$$E = \frac{\phi}{t \times 10^8}$$

where E is the voltage in volts generated in the conductor, ϕ is the total flux cut, and t is the time in seconds during which the field cutting takes place.

When the conductor consists of several turns in the form of a coil and when the magnetic field is not uniform or is not cut at a uniform rate, the formula becomes more complex.

The polarity of the induced voltage is always in opposition to the force that produces it. To illustrate this, take a wire coil wound around a simple form such as that shown in Fig. 8-3. Across the coil connect a galvanometer to complete the circuit, so that there will be current flow when a voltage is induced. When the north pole of the magnet is inserted into the center of the coil as shown, an emf is

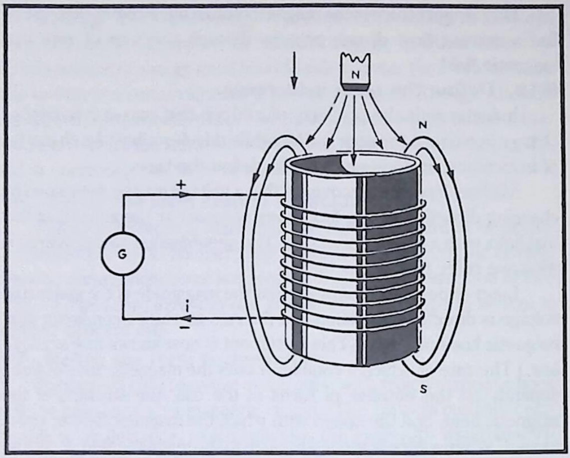


Fig. 8-3. A simple coil.

induced. The current will flow in the direction indicated by the arrow labeled i. As far as the external circuit is concerned, polarity of the induced voltage is as shown, the top lead being positive and the lower being negative. This causes the top end of the coil to appear as a north pole, which opposes the downward directon of the magnet. The induced polarity of the coil must be the same as that of the approaching magnetic pole; otherwise it would be necessary only to start a magnetic pole into the coil and, upon its inducing an opposite pole in the coil, the magnet would be drawn in, inducing additional emf without work. This would be a "perpetual motion" machine and would provide an unlimited source of energy without consuming energy—a condition that is contrary to the law of conservation of energy.

Next, consider a wire moving downward with its length perpendicular to a magnetic field which runs from left to right, as shown in Fig. 8-4. Think of the lines as being distorted as though they were rubber bands and were wrapping themselves around the wire. These lines of force would encircle the wire in a counterclockwise direction. Cutting the lines of force induces a voltage along the wire, so that current flows. If the circle marked with the X is considered

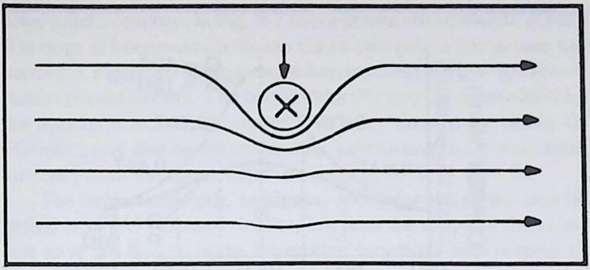


Fig. 8-4. Moving wire representation.

the cross section of a conductor going through the page, current flow would be away from you and down into the page.

8-13 What is the Q of a circuit? How is it affected by the circuit resistance? How does the Q of a circuit affect bandwidth?

During the time the magnetic field is being established in an inductor, the ratio of the energy stored to the energy lost is referred to as the ratio of quality, or Q. Sometimes the term is referred to as the coil's figure of merit. The Q of the inductor is equal to the ratio of the inductive reactance to the effective resistance in series with it, and it approaches a high value as R approaches a low value. Thus, the more effecient the coil, the lower the losses in it and the higher the Q.

In terms of the impedance triangle in Fig. 8-5, Q is equal to the tangent of the phase angle between the hypotenuse (Z) and base (R).

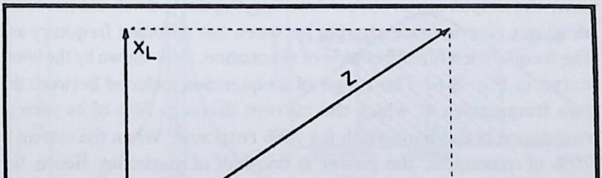


Fig. 8-5. Impedance triangle.

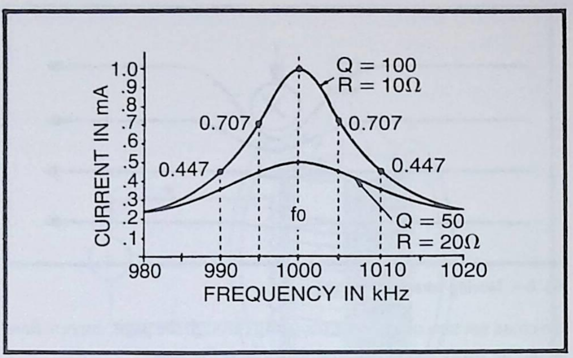


Fig. 8-6. Q curve.

As phase angle approaches 90° tan θ approaches infinity, and the coil losses approach zero.

The Q of a coil does not vary extensively within the operating limits of a circuit. It would seem, from the equation $Q = X_L/R$ that since inductive reactance is a direct function of frequency, Q also must be a direct function of frequency. Such is not the case, however. It is true that as frequency increases, the inductive reactance increases; but as frequency increases, the effective resistance of the coil also increases. Since Q is an inverse function of the effective resistance, the net effect of a frequency increase is to leave Q relatively unchanged.

The higher the Q, the sharper the bandwidth. If the circuit Q is low, the amplification at resonance is relatively small and the circuit does not discriminate sharply between the resonant frequency and the frequencies on either side of resonance, as is shown by the lower curve in Fig. 8-6. The range of frequencies included between the two frequencies at which the current drops to 70% of its value at resonance is the bandwidth for 70% response. When the current is 70% of maximum, the power is one-half of maximum. Hence, the bandwidth is often referred to as the half-power bandwidth.

Frequencies beyond the 70% or half-power point are considered to produce no usable output. The series resonant circuit is seen to have two half-power points—one above resonance and one below. The two points are designated upper cutoff frequency and

lower cutoff frequency. In Fig. 8-7 these points are labeled *f1* and *f2*. The range of frequencies between these two points comprises the bandwidth. Figure 8-7 illustrates the bandwidths for high- and low-Q series resonant circuits. The bandwidths (B) may be determined by the equation $B = f_0/Q$, or center frequency divided by circuit Q. Bandwidth may also be determined by subtracting the lower cutoff frequency from the upper cutoff frequency, or $B = f2 - f1$.

The terms bandwidth, bandpass, and selectivity may also be applied to parallel resonant circuits, because the shape of the resonant curve that describes the impedance variations with respect to frequency has the same general structure as the curve used for series resonant curves. Curves of a high-Q and a low-Q circuit are shown in Fig. 8-8. Notice that in the high-Q circuit, the selectivity is good. The low-Q curve shows a wider bandwidth, hence poor selectivity. A comparison pertaining to the overall merit of each curve cannot be made, because each curve has its advantages and disadvantages when applied to a particular circuit.

8-14 What is resonant frequency and how is it determined?

The reactance of capacitors and inductors is determined by their physical construction and the applied frequency. X_L varies directly with frequency and X_C varies inversely with frequency. Due

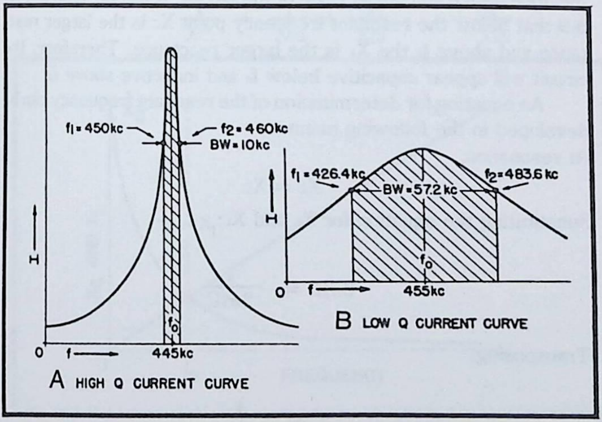


Fig. 8-7. High-Q (A) and low-Q (B) current curves showing bandwidth.

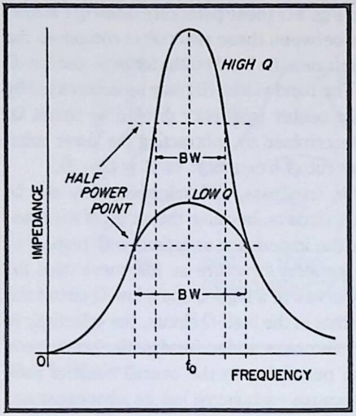


Fig. 8-8. High-Q and low-Q curves showing selectivity.

to this relationship any combination of inductance and capacitance will have a specific frequency at which the reactances will be equal. The relationship of X_L, X_C, frequency, and the resonant frequency point f_o is shown in Fig. 8-9.

In a series RLC circuit the largest reactance value determines the appearance and phase angle of the circuit. It can be seen in Fig. 8-9 that below the resonant frequency point X_C is the larger reactance and above f_o the X_L is the larger reactance. Therefore, the circuit will appear capacitive below f_o and inductive above f_o.

An equation for determination of the resonant frequency can be developed in the following manner:

At resonance,

$$X_L = X_C$$

Substituting the equation for X_L and X_C:

$$2\pi fL = \frac{1}{2\pi fC}$$

Transposing:

$$f^2 = \frac{1}{4\pi^2 LC}$$

Solving for f:

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

where:
f_o = resonant frequency in Hz
L = inductance in henrys
C = capacitance in farads

8-15 How are capacitive reactances in series computed? In parallel?

Capacitive reactances in series or parallel are computed in much the same way as resistances in series or parallel. If two capacitors each possessing 25 ohms of reactance are connected in series, the total reactance is 50 ohms. If the same two reactances are connected in parallel, the total reactance would be 12.5 ohms. In equation form:

For series:

$$X_{CT} = X_{C1} + X_{C2} + X_{C3} + \ldots . X_{Cn}$$

For parallel:

$$X_{CT} = \frac{1}{\frac{1}{X_{C1}} + \frac{1}{X_{C2}} + \frac{1}{X_{C3}} \ldots . \frac{1}{X_{Cn}}}$$

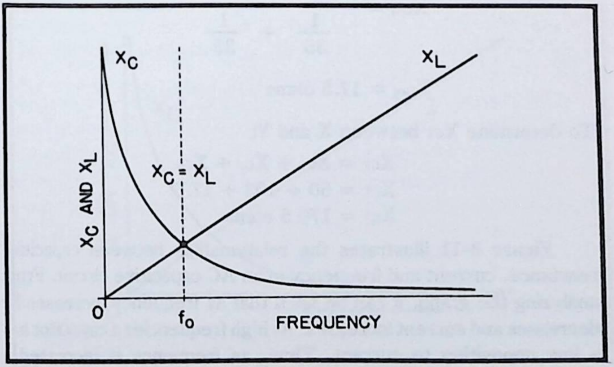


Fig. 8-9. Frequency curve.

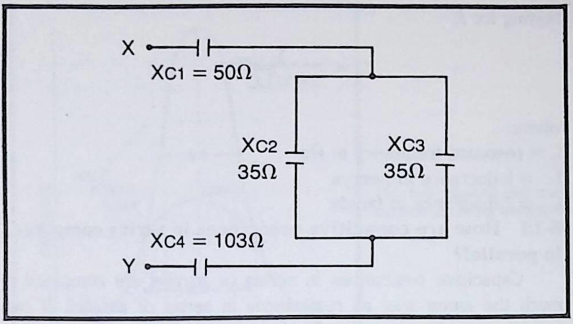


Fig. 8-10. Graphic for Question 8-15.

As an example, using the circuit of Fig. 8-10, suppose you are asked to determine the total capacitive reactance between points X and Y. Use the same method of analysis as you would for resistors as follows: Determine X_{Ceq} between X_{C2} and X_{C3}:

$$X_{Ceq} = \frac{1}{\dfrac{1}{X_{C2}} + \dfrac{1}{X_{C3}}}$$

$$X_{Ceq} = \frac{1}{\dfrac{1}{35} + \dfrac{1}{35}}$$

$$X_{Ceq} = 17.5 \text{ ohms}$$

To determine X_{CT} between X and Y:

$$X_{CT} = X_{C1} + X_{C4} + X_{Ceq}$$
$$X_{CT} = 50 + 103 + 17.5$$
$$X_{CT} = 170.5 \text{ ohms}$$

Figure 8-11 illustrates the relationships between capacitive reactance, current and frequency in an AC capacitive circuit. From analyzing the graph, it can be seen that as frequency increases X_C decreases and current increases. At high frequencies a capacitor has a low opposition to current. Thus, as frequency is increased a capacitor's characteristics approach those of a short circuit. On the

other hand as the frequency is decreased the opposition (X_C) increases and the current decreases. At the point marked zero frequency (represents DC) the capacitor exhibits the characteristics of an open circuit, i.e., extremely high opposition and no circuit current.

8-16 How are inductive reactances in series computed? In parallel?

When series connected inductors ar well shielded, or located far enough apart to make the effects of mutual inductance negligible, the equivalent of total inductance of the circuit is the algebraic sum of the individual inductances. This is expressed mathematically as:

$$L_T + L_1 + L_2 + L_3 + \ldots . L_n$$

where: L_t = total inductance in henry, and
L_1, etc. = individual inductances in henrys.

With parallel connected inductors, the total inductance, L_t, of inductors is calculated in the same manner that the total resistance of resistors in parallel is calculated, provided the coefficient of coupling is zero. If there is no mutual inductance, then for inductors connected in parallel the reciprocal of the total inductance equals the sum of the reciprocals of the individual inductances. Mathematically, this is:

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots . \frac{1}{L_n}$$

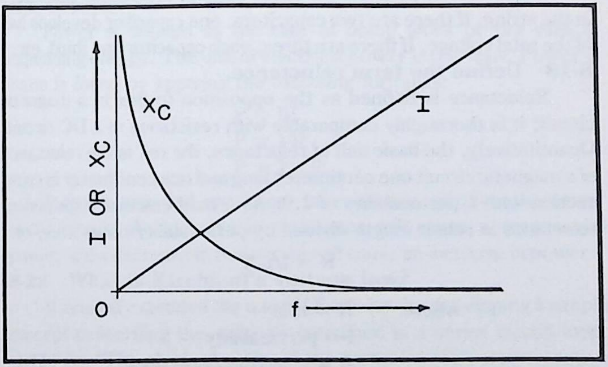


Fig. 8-11. Capacitive circuit relationships.

or

$$L_T = \cfrac{1}{\cfrac{1}{L_1} + \cfrac{1}{L_2} + \cfrac{1}{L_3} + \ldots \cfrac{1}{L_n}}$$

When there are only two inductors in parallel (and no magnetic coupling) the product over the sum method may be employed, as follows:

$$L_T = \frac{L_1 L_2}{L_1 + L_2}$$

The formula for inductive reactance in a circuit is given as:

$$X_L = 2\pi f L$$

where: f = frequency of the applied voltage in Hz
L = inductance in henrys

To determine the inductive reactance, whether or not the inductors are in series or in parallel, we must first calculate the value of the inductance as indicated above. Then, by application of the formula for inductive reactance, the correct answer can be obtained.

8-17 The voltage drop across an individual capacitor of a series string, when the string is placed across a source voltage, is proportional to what factors?

It is inversely proportional to the number of *identical* capacitors in the string. If there are two capacitors, one capacitor develops half of the total voltage. If there are three, each capacitor one third, etc.

8-18 Define the term reluctance.

Reluctance is defined as the opposition to flux in a magnetic circuit; it is thoroughly comparable with resistance in a DC circuit. Quantitatively, the basic unit of reluctance, the rel, is the reluctance of a magnetic circuit one centimeter long and one centimeter in cross section with a permeability of 1.0. As a mathematical expression, reluctance in rels is length divided by permeability times area, or:

$$R = l/\mu A$$

where: R = rels
l = permeability
A = cross-sectional area

8-19 What factors determine the charge stored in a capacitor?

Stated as a formula, charge is equal to capacitance times voltage. But since several factors determine capacitance, so too must these factors influence the total charge. Similarly, the higher the dielectric constant (k), the greater the stored charge (Q). The charge depends on capacitance, area of plates, distance between plates, dielectric constant, applied voltage, and duration of applied voltage. The equation for charge becomes $Q = 0.2246E\ (kA/d)$, where E is voltage, k is dielectric constant, A is area of plates, and d is the distance between plates.

8-20 You are given two identical mica capacitors of 0.1 μF. One is charged to a potential of 125V and disconnected from the charging circuit. The charged capacitor is then connected in parallel with the uncharged one. What voltage will appear across the pair?

The voltage across the two will be approximately half the total voltage of the first capacitor before making the connection. The uncharged capacitor acts to discharge the charged one while it is actually being charged; thus the voltage is equally distributed between the two capacitors. The ultimate charge will be slightly less than 62.5V because the act of charging a capacitor takes a small amount of energy.

8-21 How is power affected by a change in the resistance of a circuit?

Power is defined as the rate of doing work or the rate of expending energy. The unit of electrical power is the watt. Power in watts is found by applying the following formulas:

$$P = IE$$
$$P = I^2R$$
$$P = E^2/R$$

It can be seen that any change in resistance will affect the power of the circuit. An increase in resistance will cause a decrease in power, and a decrease in resistance will cause an increase in power.

8-22 What is Kirchhoff's voltage law?

Kirchhoff extended the use of Ohm's law by developing a simple concept concerning the voltages contained in a series circuit loop, stated as: "The algebraic sum of the instantaneous electromotive forces (EMFs) and voltage drops around any closed circuit loop is

zero." Through the use of Kirchhoff's law, circuit problems can be solved which would be difficult and often impossible with only a knowledge of Ohm's law. When the law is properly applied, an equation can be set up for a closed loop and the unknown circuit values may be calculated.

8-23 What is Kirchhoff's current law?

The division of current in a parallel network follows a definite pattern. This pattern is described by Kirchhoff's current law: "The algebraic sum of the currents entering and leaving any junction of conductors is equal to zero." The law can be stated mathematically as:

$$I_a + I_b + \ldots I_n = 0$$

where: I_a, I_b, etc. are the currents entering and leaving the junction. Currents entering the junction are assumed to be positive, and currents leaving the junction are considered negative. When solving a problem using this equation, the currents must be placed into the equation with the proper polarity signs attached.

8-24 How is current determined in a parallel RLC network in which $X_L = X_C$?

In a parallel network, the voltage across each component is equal to the applied voltage. The current in the inductive branch will *lag* the applied AC voltage by 90°, while the current in the capacitive branch will *lead* the applied AC voltage by 90°. The result is that these two reactive components tend to cancel each other, and cause a net combined current flow of zero. Therefore, the only current flow through the circuit would be through the resistive element. When $X_L = X_C$ in a parallel circuit, it is referred to as *parallel resonance*.

If the inductive reactance and the capacitive reactance are not equal, current flow in the circuit can be calculated by the current vector method or by the admittance method.

8-25 What is the impedance of a parallel circuit composed of a pure inductance and a pure capacitance at resonance? Of a series circuit at resonance?

In an ideal parallel resonant circuit, the line current is zero. Since impedance is equal to applied voltage divided by circuit current (which in this case is zero) the impedance must approach infinity.

In this series resonant circuit, the impedance is equal to the resistance in the circuit. If there is pure capacitance and pure inductance with no resistive elements, the resistance can be as-

sumed to be zero (or near zero), and the impedance is likewise close to zero.

8-26 Determine the resonant frequency of a series RLC circuit consisting of an 80 μF capacitor, 10 μH coil, and a 10 ohm resistor. How do the calculations differ for a parallel RLC circuit?

The series RLC problem is solved using the equation:

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

$$f_o = \frac{1}{6.28\sqrt{80 \times 10 \times 10^{-12}}}$$

$$f_o = \frac{1 \times 10^6}{177.5}$$

$$f_o = 5.63 \text{ kHz}$$

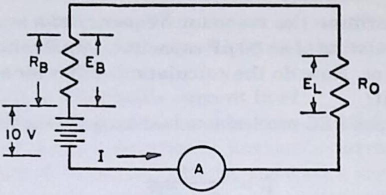
Thus, when a frequency of 5.63 kHz is applied to the circuit, the capacitive and inductive reactances will be equal.

The formula used to determine the resonant frequency in a parallel RLC circuit is the same as the one used for a series circuit.

8-27 Why is impedance matching between electrical devices an important factor? Is it always to be desired? Can it always be attained in practice?

In the transfer of power from electrical sources to their load, the impedance of the load must equal or match the internal impedance of the source for maximum transfer of power. The simple DC circuit and table of Fig. 8-12 will illustrate this principle. A 10V battery with an internal resistance R_B of 1 ohm feeds an external circuit of variable resistance R_O. When R_O is 4 ohms, the total resistance of the circuit is 5 ohms ($R_B + R_O$), the current in the circuit is 2 amps, and the voltage drop across the load (E) is 8V. The power absorbed by the load is E_L times I, or 16W. The power dissipated in the battery as heat is E_B, multiplied by I, or 4W.

When R_O is 3 ohms, total resistance is 4 ohms, I is 2.5 amps, and E_L is 7.5V. The power absorbed by the load is 18.75W and by the battery 6.25W. When R_O is 2 ohms, total resistance is 3 ohms, I is



E	R_B	R_O	R_T	I	E_B	E_L	P_L (WATTS)
10	1	4	5	2	2	8	16
10	1	3	4	2.5	2.5	7.5	18.75
10	1	2	3	3.33	3.33	6.67	22.2
10	1	1	2	5	5	5	25
10	1	.5	1.5	6.67	6.67	3.33	2.22
10	1	.33	1.33	7.5	7.5	2.5	18.75
10	1	.25	1.25	8	8	2	16

Fig. 8-12. Impedance matching.

3.33 amps, and E_L is 6.67V. The power absorbed by the load is 20W, and by the battery 10W. When R_0 is 1 ohm, total resistance is 2 ohms, I is 5 amps, and E_L is 5V. The power absorbed by the load is 25W, and by the battery, 25W. When R_0 is less than 1 ohm, power falls off in the load as indicated in the table. Thus, the greatest power is delivered to the load when the impedance of the load is equal to the internal impedance of the source.

To answer the question, then: Impedance matching between electrical devices is an important factor because it governs the percentage of total power delivered to the load. It is always to be desired if power transfer is a criterion of circuit performance. Unfortunately, it cannot always be achieved in practice, because impedance is frequency dependent. A 4 ohm speaker in an audio circuit, for example, will only be precisely matched to the amplifier at one frequency.

8-28 Explain the operation of a transformer.

The operation of a transformer depends on the principle of electromagnetic induction. Basically, a transformer consists of any two inductors (in separate circuits) so placed physically that the changing electro-magnetic field set up by an alternating current in one induces an alternating emf in the other. Thus, mutual inductance exists between the coils, and the two circuits are said to be inductively coupled.

Figure 8-13 shows such a basic transformer connected between an AC generator and a resistance load. The coil connected to the source of power is called the primary winding, and the coil connected to the load is called the secondary winding. The power delivered by the generator passes through the transformer and is delivered to the load, although no direct connection exists between the primary and the secondary winding, or between generator and load. The connection that does exist is the flux linkage between the coils, and the power is effectively transferred by induction. Thus, the power consumed by the primary is equal to the power delivered by the secondary, and $P_P = P_S$. If the coils of a transformer were completely shielded from each other, no power transfer could take place and the transformer would be useless.

8-29 What is the most important factor in the efficiency of a transformer? What factors must be considered in design to obtain maximum transformer efficiency?

For a maximum transfer of power from the primary to the secondary of the transformer the flux linkage must be complete; that is, all of the lines of force set up by the primary winding must link the secondary winding. For this reason, the secondary is often wound directly on the primary with only protective insulation separating the two coils. Then, since the reluctance of air is very great and its permeability small, the introduction of a soft steel core of high

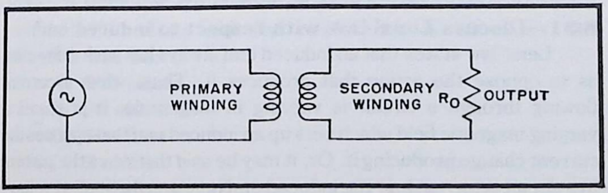


Fig. 8-13. Basic transformer circuit.

permeability in the transformer increases the flux linkage between the coils and makes possible a high percentage of power transfer. Even with the use of high permeability cores, a few of the flux lines fail to link the secondary winding and are effectively lost, constituting a flux leakage which prevents the transformer from being a perfect conductor of power from the generator to the load.

Practical iron-core transformers are not, of course, 100% efficient, but when carefully designed they show a high efficiency, ranging from 95% to 98%. The high efficiency is possible in a transformer because of the careful attention devoted to minimizing the effective losses due to flux leakage, hysteresis, eddy currents, flux saturation of the core, as well as the copper losses of the coil windings and losses from distributed capacitance.

8-30 How does the number of turns ratio affect the secondary voltage in a transformer?

The magnitude of the voltage induced in either side of a transformer depends directly upon the number of turns. Thus, the back emf induced by the changing current in the primary is not equal to the emf induced in the secondary unless the number of turns in the primary equals the number in the secondary. Furthermore, since the back emf in the primary is equal to the applied voltage, a ratio may be set up to determine the emf induced in the secondary in terms of the applied voltage and the turns ratio of the two coils. Therefore:

$$\frac{E_p}{N_p} = \frac{E_S}{N_S}$$

Where:

E_p = the voltage applied to the primary
N_P = the number of turns in the primary
E_S = the voltage induced in the secondary
N_S = the number of turns in the secondary

8-31 Discuss Lenz' law with respect to induced emf.

Lenz' law states that an induced emf always has such a direction as to oppose the action that produces it. Thus, when a current flowing through a circuit is varying in magnitude, it produces a varying magnetic field which sets up an induced emf that opposes the current change producing it. Or, it may be said that when the current in a circuit is increasing, the induced emf opposes the applied voltage and tends to keep the current from increasing; and when the current

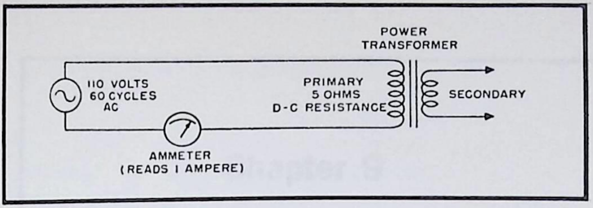


Fig. 8-14. Primary resistance.

is decreasing, the induced emf aids the line voltage and tends to keep the current from decreasing.

The effect of counter emf may be observed experimentally in that an alternating current through an inductor is opposed by a force much greater than its simple DC resistance. For example, the DC resistance of the primary of an ordinary power transformer used in a typical application may be 5 ohms. As in Fig. 8-14, this primary is connected directly to 115V AC outlet. From Ohm's law:

$$I = \frac{E}{R} = \frac{110}{5}$$

$$I = 22 \text{ amperes}$$

Using this approach, the current is calculated to be 22 amperes, but when measured, the current is actually found to be approximately 1 ampere. It is apparent that some opposition other than the 5-ohm resistance is present in the AC circuit. This opposition is the counter emf. If by mistake such a transformer is connected to a 115V DC line, the current through the primary of the transformer would be 22 amperes, and the transformer would quickly burn up. Hence, Ohm's law for DC circuits must be modified to include this effect of electrical inertia present in AC circuits.

8-32 If the capacitive reactance of a series resonant circuit is 2,000 ohms and the resistance is 10 ohms, the circuit 0 will be:

A. 500 ohms
B. 20 ohms
C. 50 ohms
D. 5 ohms
E. 200 ohms

Answer: *E*.

Chapter 9

Circuit Components

In order to pass the FCC exam, you should have a good idea of how all basic electronic components function—that is, their operating characteristics, ratings, advantages, disadvantages, etc., as well as terminology. You can be sure of questions on capacitors, resistors, inductors, solid-state diodes and other solid state components, vacuum tubes, and crystals.

Several questions prepared from FCC study guides are presented here, along with the answers you may be expected to know.

9-1 State the value and tolerance of a resistor that is color-coded as follows: red, black, orange, and gold.

The resistor in question would have a value of 20,000Ω (20K) and a tolerance (possible error) of 5%. The color bands on a resistor are read from left to right. Hold the resistor horizontally so the color band closest to the resistor end is to your left. The first band is the first digit of the value, the second band is the second digit, and the third band tells the number of zeros to add to the first two digits. The fourth band gives the tolerance. The first band in the referenced resistor is red, which represents the digit 2. The second band is black, which stands for 0. The third band, orange, tells us that three zeros follow the first two digits. So we have, from left to right, the digits 2, 0, and 000, which gives us 20,000Ω.

The tolerance band (if any) is usually silver or gold. Silver identifies the tolerance as 10Ω. Gold is 5%. No tolerance band at all

means the resistor's tolerance is ±20%. The color codes for resistors are shown in Fig. 9-1. The coding system shown at the left is that adopted by the Electronic Industries Association (EIA); the system at the right is the older Joint Army/Navy (JAN) system. Unless you plan to work with military surplus equipment, you'd do well to remember the EIA system only.

9-2 Using the EIA standard 6-dot color system, what would be the value and tolerance of a capacitor whose first-row colors are (left to right) white, red, and green, and whose second-row colors are green, silver, and red?

The value of this capacitor would be 2500 pF. The tolerance would be ±5%. The EIA 6-dot capacitor color-coding system involves the reading of two rows of three dots each. As shown in Fig. 9-2, the top row of dots is marked with arrowheads to enable easy orientation by the reader. The capacitor is held so that the arrows are on the top row and point to the right. The upper left dot identifies the capacitor type. The second and third colors of the top row identify the first and second numbers of the value. The lower right number (second row) identifies the multiplier, and the dot on the lower center position is the tolerance of error. The final dot (lower left) identifies the class of capacitor or any other special characteristics , such as temperature coefficient or methods of testing.

9-3 What is the effect of adding an iron core to an air core inductance?

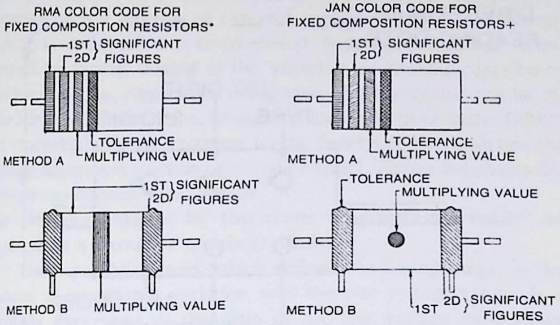
When an iron core is inserted into the coil (Fig. 9-3), the inductance of the coil becomes the product of the core's permeability and the original inductance of the air core coil. As a formula

$$L = \mu L_0$$

where L_0 is the inductance of the coil with an air core, and μ is the permeability of the iron core.

9-4 What would be the effect of a shorted turn in a coil?

The shorted turn is isolated from the main coil and acts as a transformer secondary winding. Since one turn has almost zero resistance, the induced current in that single shorted winding is quite high. The excessive current through the single turn could generate enough heat to burn through the surrounding insulation, destroying the entire coil.



NOTES

*INSULATED FIXED COMPOSITION RESISTORS WITH AXIAL LEADS ARE DESIGNATED BY A NATURAL TAN BACKGROUND COLOR NON-INSULATED FIXED COMPOSITION RESISTORS WITH AXIAL LEADS ARE DESIGNATED BY A BLACK BACKGROUND.

+RESISTORS WITH AXIAL LEADS ARE INSULATED. RESISTORS WITH RADIAL LEADS ARE NON-INSULATED.

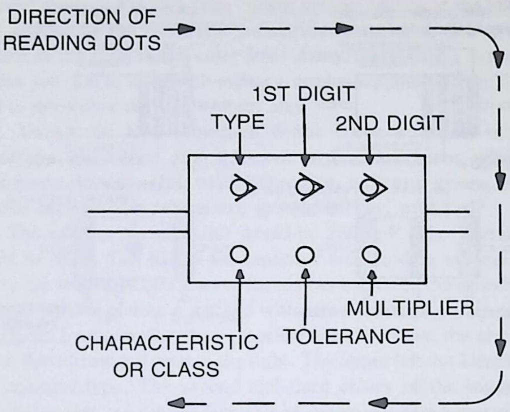
RAMA RADIO MANUFACTURERS ASSOCIATION

JAN JOINT ARMY-NAVY

THESE COLOR CODES GIVE ALL RESISTANCE VALUES IN OHMS.

COLOR	SIGNIFICANT FIGURE	MULTIPLYING VALUE	TOLERANCE (%)
BLACK	0	1	
BROWN	1	10	
RED	2	100	
ORANGE	3	1,000	
YELLOW	4	10,000	
GREEN	5	100,000	
BLUE	6	1,000,000	
VIOLET	7	10,000,000	
GRAY	8	100,000,000	
WHITE	9	1,000,000,000	
GOLD	-	01	± 5
SILVER	-	001	±10
NO COLOR	-		±20

Fig. 9-1. Resistor color codes.



TYPE	COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (PERCENT)	CHARACTERISTIC OR CLASS
JAN, MICA	BLACK	0	0	1.0		APPLIES TO
	BROWN	1	1	10	±1	TEMPERATURE
	RED	2	2	100	±2	COEFFICIENT
	ORANGE	3	3	1,000	±3	OR METHODS
	YELLOW	4	4	10,000	±4	OF TESTING
	GREEN	5	5	100,000	±5	
	BLUE	6	6	1,000,000	±6	
	VIOLET	7	7	10,000,000	±7	
	GRAY	8	8	100,000,000	±8	
EIA, MICA	WHITE	9	9	1,000,000,000	±9	
	GOLD			.1		
MOLDED PAPER	SILVER			.01	±10	
	BODY				±20	

Fig. 9-2. Capacitor dot codes.

9-5 What characteristic of a varactor diode makes the device desirable in applications involving tuning or harmonic generation?

Ordinarily, PN junctions in diodes exhibit capacitance properties. The depletion area represents a dielectric and the adjacent semiconductor material represents two conductive plates. Increasing reverse bias decreases this capacitance while increasing forward bias increases it. When forward bias is large enough to overcome the

barrier potential, high forward conduction destroys the capacitance effect, except at very high frequencies. Therefore, the effective capacitance is a function of external applied voltage. This characteristic is undesirable in conventional diode operation, but is enhanced by special doping in the varactor or variable-capacitance (varicap) diodes. Application categories of the varactor can be divided into two main types, tuning and harmonic generation. Different characteristics are required by the two types but both use the voltage dependent junction capacitance effect. Figure 9-4 shows the voltage capacitance relationships.

9-6 What is meant by the term "capacitance ratio" as applied to a varactor (tuning) diode?

The capacitance ratio, which defines the tuning range, is the amount of capacitance variation over the bias voltage range. It is normally expressed as the ratio of the low voltage capacitance divided by the high voltage capacitance. For example, a typical specification which reads $C_4/C_{60} = 3$ indicates that the capacitance value at 4 volts is 3 times the capacitance value at 60 volts. The high voltage in the ratio is usually the minimum breakdown voltage specification. A 4 volt lower limit is quite common since it describes the approximate lower limit of linear operation for most devices. The

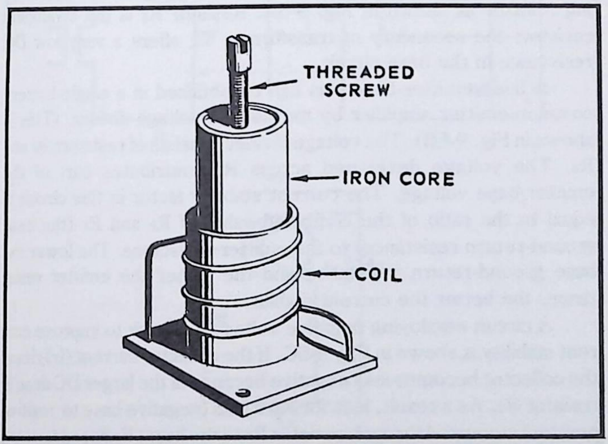


Fig. 9-3. Iron-core coil.

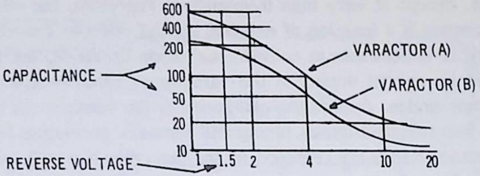


Fig. 9-4. Voltage/capacitance relationships.

capacitance ratio of tuning diodes varies in accordance with construction.

9-7 How may current stability be obtained in transistorized amplifiers? Illustrate your answer by drawing simple cirucit diagrams of the following types of amplifiers:

Common emitter

Fixed emitter-base bias

Negative voltage feedback

One method of obtaining good current stability in a common-emitter amplifier is by using near-zero base resistance and a swamping resistor as shown in Fig. 9-5A. Resistor R_E is the swamping resistor; the secondary of transformer T1 offers a very low DC resistance in the base circuit.

A fixed emitter-base bias can be obtained in a single-battery common-emitter amplifier by means of a voltage divider. (This is shown in Fig. 9-5B). The voltage divider consists of resistors R_F and R_B. The voltage developed across R_B contributes part of the emitter-base voltage. The current stability factor in this circuit is equal to the ratio of the combined value of R_B and R_F (the base ground-return resistance) to the emitter resistance. The lower the base ground-return resistance and the higher the emitter resistance, the better the current stability.

A circuit employing negative voltage feedback to improve current stability is shown in Fig. 9-5C. If the collector current (I_C) rises, the collector becomes less negative because of the larger DC drop in resistor R_C. As a result, less forward bias (negative base to positive emitter) is coupled through resistor R_F to the base. Reduced forward bias then reduces the collector current.

9-8 What is a junction tetrode transistor? How does it differ from other transistors in base resistance and operating frequency?

The highest frequency that can be amplified by a 3-terminal junction transistor is limited by the input capacitance, and particularly, the output capacitance of the transistor. One method for reducing these capacitances is to reduce the size of the transistor's semiconductor material. However, this method is physically limited because the semiconductor material must be large enough so that leads may be attached to the three regions. A second method is to restrict transistor action to a small portion of the semiconductor material, so that the effect of a small-size transistor with low input and output capacitance is obtained. To employ the latter method, a tetrode (4-terminal) transistor must be used.

A tetrode transistor is shown in Fig. 9-6. The tetrode transistor is constructed in the same manner as the 3-terminal (pnp or npn) junction transistor, except for the addition of a second terminal to the

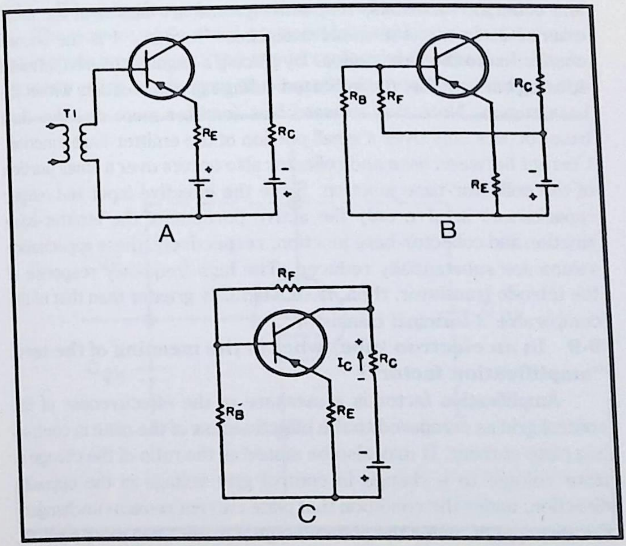


Fig. 9-5. Transistorized amplifiers: (A) common emitter, (B) fixed emitter, and (C) negative voltage feedback.

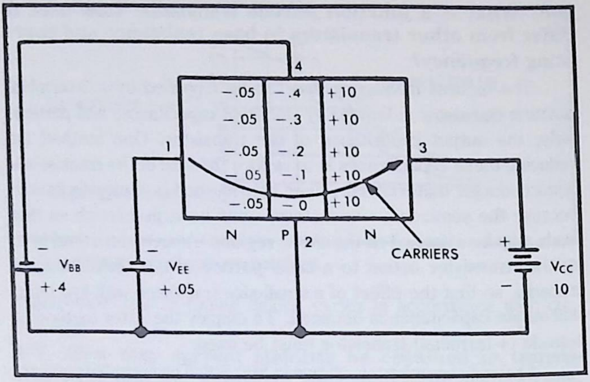


Fig. 9-6. Representation of a tetrode transistor.

base region. Terminal 1, 2, and 3 are the conventional emitter, base, and collector terminals, respectively, and are biased in the same manner as in the 3-terminal transistor. Terminal 4 is the second connection to the base region. By placing a negative bias on terminal 4, using battery V_{BB}, the indicated voltage gradient occurs within the base region. Note that forward bias (emitter more negative than base) occurs only over a small portion of the emitter-base junction. Current between base and collector also occurs over a small portion of the collector-base junction. Since the effective input and output capacitances involve only the active portions of the emitter-base junction and collector-base junction, respectively, these capacitance values are substantially reduced. The high-frequency response of the tetrode transistor, then, is substantially greater than that of the comparable 3-terminal transistor.

9-9 In an electron tube, what is the meaning of the term "amplification factor"?

Amplification factor is a measure of the effectiveness of the control grid as compared to the effectiveness of the plate in controlling plate current. It may also be stated as the ratio of the change in plate voltage to a change in control grid voltage in the opposite direction, under the condition that plate current remains unchanged. For example, if, when the plate voltage is made 1 volt more positive, the control grid voltage must be made 0.1 volt more negative (with

respect to the cathode) to hold plate current unchanged, the amplification factor is 1 divided by 0.1, or 10. In other words, a small variation in grid to cathode voltage has the same effect on plate current as a large plate voltage change—the latter equal to the product of the grid voltage change and amplification factor.

9-10 What is "interelectrode capacitance"?

The grid, plate, and cathode of a triode form an electrostatic system, each electrode acting as one plate of a small capacitor. The capacitances are those existing between grid and plate (C_{gp}), plate and cathode (C_{pk}), and grid and cathode (C_{gk}). These capacitances are known as interelectrode capacitances and are represented in Fig. 9-7. Generally, the capacitance between grid and plate (C_{gp}) is of the most importance. In high gain radio frequency amplifier circuits, this capacitance may act to produce undesired coupling between the input circuit (the circuit between grid and cathode) and the output circuit (the circuit between plate and cathode). This coupling is undesirable in an amplifier because it may cause instability and unsatisfactory performance.

9-11 What is the primary purpose of a screen grid?

The screen grid's chief purpose is to minimize a tube's interelectrode capacitance. The triode's principal drawbacks for high-frequency work result from the capacitance existing between the

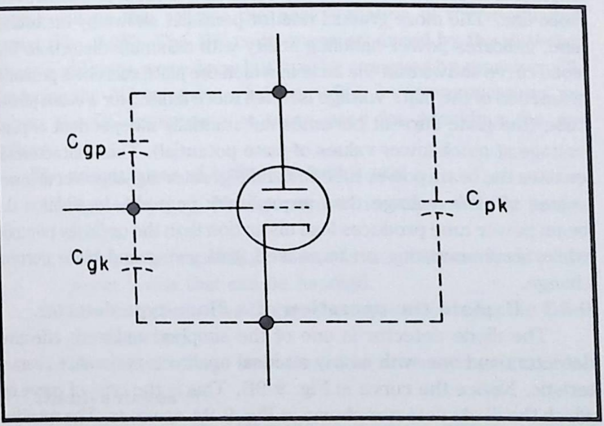


Fig. 9-7. Interelectrode capacitance.

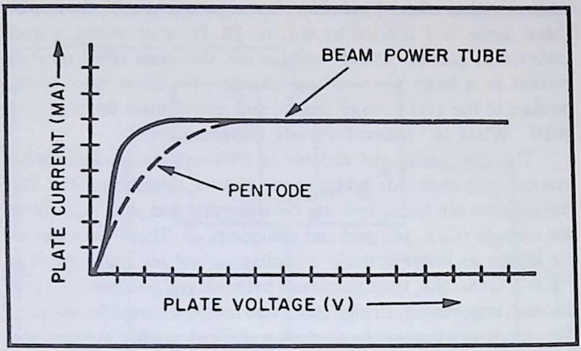


Fig. 9-8. Beam power tube characteristics.

grid and plate. The screen grid in a tetrode (and pentode), between grid and plate, diminishes this effect.

9-12 Compare the plate current capabilities of a beam power tube with a pentode.

Figure 9-8 shows the plate current and plate voltage characteristics of a beam power tube and a conventional pentode. Note the rapid rise in plate current for the beam power tube, as shown by the solid line. The more gradual rise for pentode, shown by the broken line, indicates power-handling ability with minimum distortion. The solid curve shows that the zone in which the plate current is primarily a function of the plate voltage is much more limited for a beam power tube (the plate current becomes substantially independent of plate voltage at much lower values of plate potential). This characteristic enables the beam power tube to handle greater signal power at lower values of plate voltage than an ordinary pentode. In addition the beam power tube produces less distortion than the ordinary pentode while accommodating an increased grid swing and plate current change.

9-13 Explain the operation of a diode-type detector.

The diode detector is one of the simplest and most effective detectors and one with nearly an ideal nonlinear resistance characteristic. Notice the curve in Fig. 9-9B. This is the type of curve on which the diode detector shown in Fig. 9-9A operates. The rounded portion of the curve is the region of low plate current and indicates

that, for small signals, the output of the detector will follow the square law. For input signals with large amplitude, however, the output of the detector will be essentially linear in the positive direction from the operating point. This type of detector is classed as a power detector since it handles large input amplitudes without much distortion.

The modulated carrier is introduced into the tuned circuit made up of LC1, which is designed so that the receiver has a high degree of selectivity. The waveshape of the input to diode plate is shown in Fig. 9-9C. As a diode conducts only during positive half-cycles, the circuit removes all the negative half-cycles and gives the result shown in Fig. 9-9D. The average output is shown in Fig. 9-9E.

Although the average input voltage is zero, the average output voltage across R always varies above zero and has an average voltage of 50% of the capacitor's average charge, times the peak voltage for any positive half-cycle.

The low-pass filter made up of capacitor C2 and resistor R removes the rf (carrier frequency), which serves no useful purpose in the receiver. Capacitor C2 charges rapidly to the peak voltage through the small resistance of R. The sizes of R and C2 normally bring about a relatively short time constant at the audio frequency and a very long time constant at the radio frequency carrying the audio intelligence. The resultant output with C2 in the circuit is a varying voltage that follows the peak variation of the modulated carrier (Fig. 9-9F). The DC component produced by the detector circuit is still in the waveshape but may be removed by capacitor C3, producing the AC waveshape in Fig. 9-9G. In communications receivers the DC component is often used for providing the agc voltage.

The **advantages** of a diode detector are:

1. High efficiency. Ninety percent is achievable by proper design.
2. High-power capability. There is no practical limit to the power levels that can be handled.
3. Low distortion. The higher the input amplitude, the lower the distortion.
4. Developed voltage can be used for automatic gain control.

Disadvantages are:

1. Power is absorbed from the input circuit, which lowers the circuit Q and decreases selectivity.

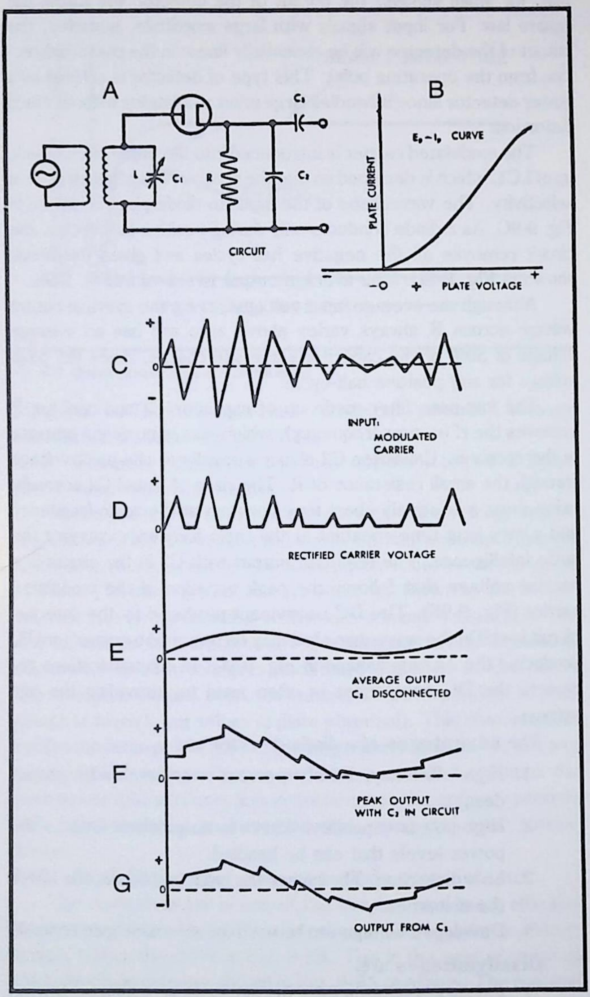


Fig. 9-9. Diode-type detector operation.

2. No amplification is possible, since the circuit is entirely passive.

9-14 Explain the operation of a vacuum-tube diode rectifier power supply and filter.

The schematic of a typical full-wave rectifier circuit using a twin diode is illustrated in Fig. 9-10. Since a directly heated rectifier tube is used, the load resistance is connected between the filament-type cathode and the centertap of the high-voltage secondary. To simplify the wiring, the metal chassis is used to complete the connection between the bottom of the load resistance and the secondary centertap. This is shown schematically by grounding each of these two points. An additional secondary winding on the power transformer supplies heater voltage to other tubes that may be contained in the equipment.

The operation of this full-wave rectifier circuit is as follows. (The individual alternations of the total secondary voltage have been numbered for identification.) During positive alternation 1, the top end of the secondary is positive with respect to ground, and the bottom end of the secondary is negative with respect to ground. Only the upper diode has the necessary positive plate voltage required for conduction. Current will flow from ground, up through the load resistor to the cathode, from the cathode to the upper diode plate, down through the top half of the transformer secondary to the

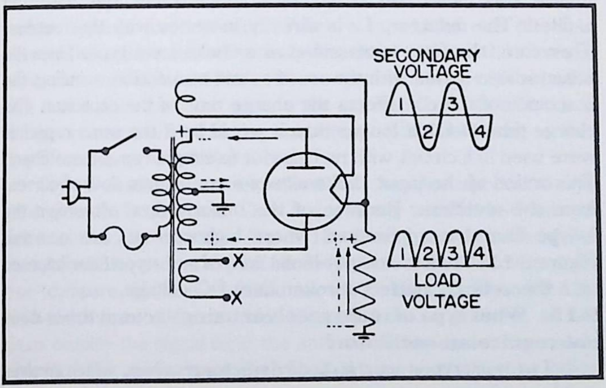


Fig. 9-10. Rectifier circuit.

centertap, and back to the bottom of the load resistor by way of the metal chassis. This current develops a pulse of voltage across the load resistor that makes the top of the resistor positive with respect to ground.

The waveform across the resistor is shown by the load-voltage alternation marked 1 in the diagram. Upon completion of the positive alternation, the polarities across the secondary winding reverse. This makes the plate of the top diode negative, causing the top diode to cut off. The bottom diode plate becomes positive, and conduction occurs over the path marked by the dotted arrows.

The important fact to note about the circuit arrangement is that current flows through the load resistance in the same direction for both positive and negative alternations of the applied sine wave.

When the output waveform from the full-wave rectifier is examined, it is seen to consist of two pulses of current or voltage for each cycle of input voltage. The ripple frequency at the output of a full-wave rectifier is therefore twice the line frequency. The high ripple frequency at the output of a full-wave rectifier is a distinct advantage. As a result of this higher pulse frequency, the output more closely approximates pure DC and is easier to filter.

The output voltage is not normally usable without being filtered because of the high ripple content. The filtering method may be inductive, capacitive, or a combination of inductive and capacitive. Figure 9-11 illustrates one simple combination type, called an L-filter. The inductor, L, is directly in series with the rectifier. Therefore, the filter is classified as a choke-input type. Since the inductor is in series with the rectifier and transformer winding, the reactance of the coil affects the charge time of the capacitor. The charge time of C1 is longer than it would be if the same capacitor were used in a circuit with no inductor (a simple capacitance filter). This action of the input choke allows a continuous flow of current from the rectifiers. Because of the uniform flow of current the L-type filter has applications where high currents are incurred. Figure 9-11 shows the output (solid line) of an L-type filter imposed on a theoretically perfect (broken line) DC voltage.

9-15 What type of radio receiver using vacuum tubes does not require an oscillator?

Two such types are the diode detector receiver, which involves nothing more than a tuned circuit and a rectifier, and the tuned-rf

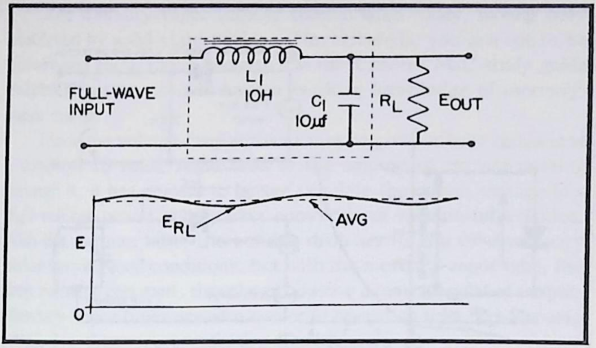


fig. 9-11. The L-type filter.

receiver, which is composed of a number of cascaded rf amplifiers feeding a detector stage.

9-16 In radio receivers, what is another name for "mixer?"

In the case of radio receivers, the term *first detector* is also employed.

9-17 Describe the operation of a crystal diode detector.

A small piece of germanium, silicon, galena, iron pyrite, quartz, or carborundum is capable of providing the nonlinear diode characteristic required for detection. When a crystal of one of these elements is in direct contact with a sharp-pointed wire, the arrangement offers a different resistance to current from the crystal to the wire than it does from the wire to the crystal. Crystals of modern vintage are encapsulated in tiny containers with axial leads, so that they often appear much like a resistor.

Crystal detectors are excellent for detector applications at ultrahigh radio frequencies. They are typically used as both mixers and detectors, as shown in Fig. 9-12. The characteristics of the crystal diode detector are quite similar to those of the vacuum-tube type (compare the characteristic curves of Figs. 9-13 and 9-12). When used as an rf detector fed directly from an antenna, an LC circuit couples the signal from the antenna to the diode. For use in other detector applications, the rf signal may be coupled by other means.

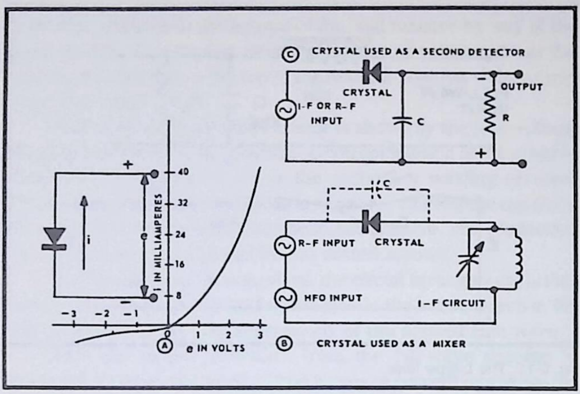


Fig. 9-12. Crystal diode detector circuit.

The detector diode conducts only during positive half-cycles of the input signal; so the diode's output is a rectified version of the modulated input. The positive peaks vary in amplitude according to the audio frequency carried on the rf signal. The average voltage output varies above zero at the audio rate. Thus, this average can be used to provide audio information by simply applying the output through a low-pass filter that will remove the rf component. In the sketches the low-pass filter consists of the resistor and capacitor. The RC network has a short time constant at the audio frequency but quite a long one at rf. The output, then, is a varying signal that follows the peak variation of the modulated carrier.

9-18 In what frequency ranges has the electron tube diode mixer found its widest application?

In past years the diode was considered the simplest mixer tube, but its noise figure (figure of merit) is not as good as the more complicated mixer circuits. Because of its low interelectrode capacitance, the diode has found wide use in VHF and UHF applications. However, the local oscillator must furnish a considerable amount of power to the diode mixer because of the low impedance of the diode tube.

9-19 What constant voltage drop can be expected across a mercury-vapor tube?

The mercury-vapor tube is seldom used today, having been obsoleted by solid-state devices. Nevertheless, you are apt to be questioned about these because the most recent FCC study guide indicates that you should have a working knowledge of mercury-vapor tubes.

Since the voltage drop across a mercury-vapor tube remains at a constant 15 volts, regardless of the amount of current passing through it, it has served to better regulate the output voltage in a high-voltage power supply over conventional vacuum-tube diodes. With the vacuum tube, the voltage drop across the tube will vary under varying load conditions, but with the mercury-vapor tube, the drop remains constant, thereby producing a more regulated output. Mercury-vapor tubes are also cooler in operation than high-vacuum tubes, but there are certain drawbacks.

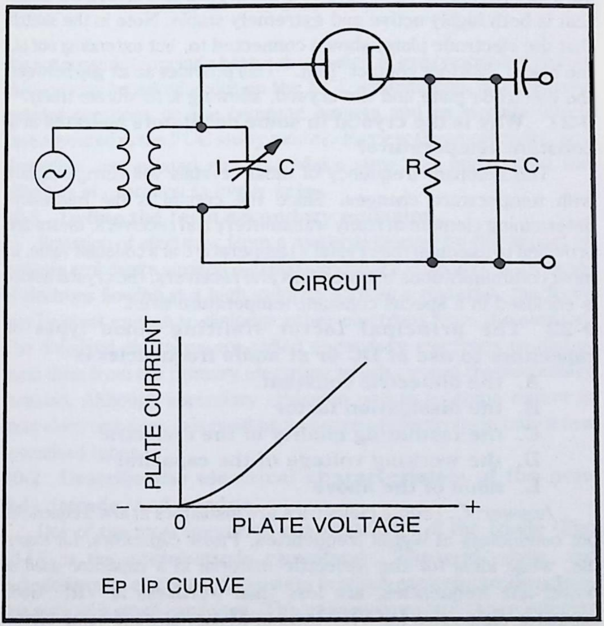


Fig. 9-13. Tube-type detector with curve.

Manufacturer's literature states that mercury-vapor tubes must be warmed up 15 or 20 seconds before high voltage is applied, or permanent damage to the tube will occur. In practice, it is usually safer to allow a full minute of warm-up time due to variations in tube performance. Other disadvantages have just about eliminated use of the mercury-vapor tube in modern electronics.

9-20 What crystalline substance is widely used in crystal oscillators?

The most widely used crystalline substance is quartz, which may be either natural or man-made. Quartz exhibits a characteristic called piezoelectricity, whereby an applied mechanical pressure causes generation of a voltage. The quartz is cut in slabs and mounted in holders that sandwich the crystal element between the top of the holer and one of the electrodes, which maintains a pressure on the crystal. In an oscillator the crystal acts as an LCR circuit that is both highly active and extremely stable. Note in the sketch that the electrode plate, shown connected to, but extending out of, the holder, has four contact "feet." This provides an air gap between the electrode plate and the crystal, allowing it to vibrate freely.

9-21 Why is the crystal in some oscillators operated at a constant temperature?

The resonant frequency of most crystals will change slightly with temperature changes. Since the crystal is the frequency-determining element in many transmitters and receivers, means are provided to maintain the crystal's temperature at a constant value. In most communications transmitters and receivers, the crystal holder is enclosed in a special constant-temperature oven.

9-22 The principal factor limiting some types of capacitors to use at DC or at audio frequencies is

A. the dielectric constant.
B. the dissipation factor
C. the insulating quality of the dielectric
D. the working voltage of the capacitor
E. none of the above

Answer: *C.* (Some dielectrics are insulators at low frequencies but conductors at higher frequencies. Paper capacitors, for example, while ideal for the dielectric material in a capacitor used at power-line frequencies, are less than worthless at VHF. Good capacitor dielectrics for VHF include Mylar, air, and some ceramics.)

Chapter 10

Practical Circuits

It is not possible to include here a discussion of every possible circuit that you may be asked about on the FCC examination, but we have included questions on the common circuits and on circuits which have appeared in the FCC study guides. Review these carefully, and if possible, any related circuits. Make sure you understand the principles of operation in every case.

10-1 Define the term secondary emission.

Emission of electrons from a material caused by the impact of particles striking its surface is called secondary emission. If a stream of electrons flowing at a high velocity strikes a material, the force may be great enough to dislodge other electrons from the surface. The dislodged electrons are called secondary electrons to distinguish them from the primary electrons which caused the secondary emission. Although secondary emission occurs to some extent in most electron tubes, it is used as a source of electrons in only a few specialized tubes.

10-2 Describe the electrical characteristics of the pentode, tetrode, and triode.

One of the most important characteristics of the triode (Fig. 10-1A) is the interelectrode capacitance. The grid, plate, and cathode form an electrostatic system in which each electrode acts as one plate of a small capacitor. The capacitances are those existing between grid and plate (C_{gp}), and between plate and cathode (C_{pk}),

and between grid and cathode (C_{gk}). The capacitance between grid and plate is of the most importance. In high-gain rf circuits this capacitance may produce undesired coupling between the input and output circuit. Such undesirable coupling causes instability and erratic operation.

The tetrode is shown in Fig. 10-1B. One of the principal advantages of this 4-element tube is the diminished interelectrode capacitance. This is attributable to the additional electrode (screen grid) between the control grid and the plate. The screen grid has another desirable effect in that it makes plate current practically independent of plate voltage over a specific range of operating parameters. The screen grid is operated at a positive potential with respect to the cathode, so it attracts electrons from the cathode. However, because of the coarse screen construction, most of the electrons drawn toward it pass right through to the plate. Thus, while the screen grid shields the electrons on the cathode side of the screen grid from the plate (preventing an electrostatic effect between the two), it does serve to bolster the passage of electrons in the tube.

One disadvantage of the tetrode is the increased susceptibility to secondary emission, the action of electrons being knocked loose from the plate. The presence of the screen grid causes these electrons to be drawn back toward the screen, thus reducing the plate current and limiting the useful plate voltage swing.

The pentode's extra grid serves to check the problem of secondary emission. In this device (Fig. 10-1C) an additional element (suppressor grid) is placed between the screen grid and plate. Since this element is tied internally to the cathode, its low potential shields the screen grid from the electrons bounced off the plate.

10-3 What is transit time?

Transit time is defined as the amount of time it takes for electrons to travel from the cathode to the plate in an electron tube. This time becomes critical at extremely high radio frequencies, and requires specially designed tubes with very small spacing between the cathode and the plate. Other requirements for tubes operating at higher frequencies are minimum inductance in the leads to the elements, and minimum interelectrode capacitance.

10-4 In an electronic circuit, what is meant by feedback?

There are several types of feedback, used for various purposes. Feedback is defined as a transfer of energy from the output of

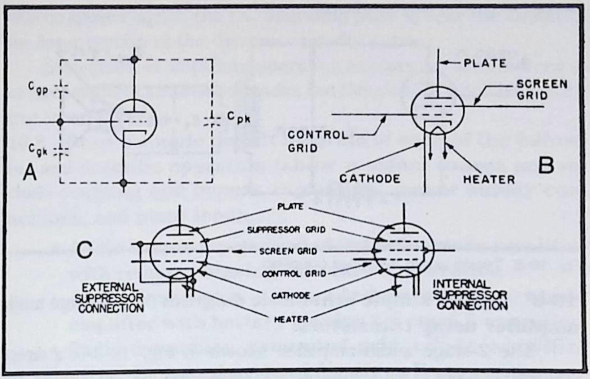


Fig. 10-1. Electrical characteristics: (A) triode, (B) tetrode, and (C) pentode.

a circuit or a device back to its input, and the most common application is in oscillators (to sustain oscillation). Inverse feedback signals in af amplifiers are 180° out of phase with the input signal being applied, and have the effect of reducing distortion in the output of the amplifier. Current feedback uses the inverse voltage developed across the cathode-biasing resistor in a triode to produce degeneration, which tends to decrease distortion in the output. Feedback may be referred to as out-of-phase, inverse, degenerative, negative, current, positive, etc.

10-5 Draw a simple schematic of a triode audio amplifier inductively coupled to a loudspeaker.

Figure 10-2 shows a triode stage inductively coupled to a loudspeaker. The inductance is used as an impedance-matching device. Because the plate resistance of an audio output tube may range from 1K to more than 20K, while the loudspeaker might be anywhere between 3.2 ohms and 16 ohms, the transformer has to be used to change the effective impedance of the output circuit. The transformer has a stepdown turns ratio that provides the speaker with a signal of the proper impedance. The output voltage of a transformer varies in direct proportion to the turns ratio. The transformer's primary impedance is usually established at twice the tube's plate resistance (r_p) to give maximum undistorted output. If the speaker is 4 ohms, the turns ratio will be about 612:1.

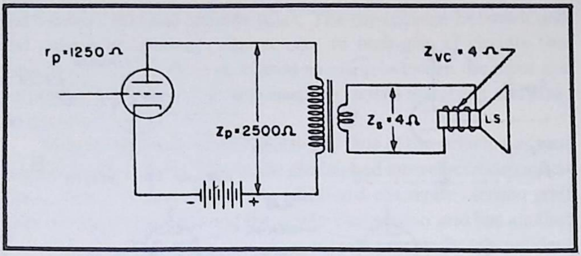


Fig. 10-2. Triode audio amplifier coupling.

10-6 Draw a simple schematic diagram of a 2-stage audio amplifier using transistors.

The 2-stage audio amplifier shown in Fig. 10-3 is a direct-coupled amplifier with built-in compensation for an interior microphone. By direct coupling transistor Q1's output to the input of Q2, use of a coupling capacitor is avoided. Coupling capacitors, like transformers, tend to attenuate the low frequencies.

Transformer T1 couples the output of the microphone (M1) to the base of transistor Q1, which is the first amplifier. Resistor R1 is the emitter swamping resistor (overcomes variations in resistance of base—emitter junction); capacitor C1 is the bypass for R1. Collector load resistor R2 develops the output signal. Capacitor C2 and resistor R3 constitute a low-pass filter. The signal is amplified again by transistor Q2. Resistor R4 produces negative feedback. Resistor R5 is the swamping resistor of the second audio amplification stage. Capacitor C3 bypasses the AC signal around resistor R5. Collector load resistor R6 develops the output signal.

10-7 Linear amplification employs what class of amplifier?

The linear amplifier is a class A type. A class A amplifier is defined as an amplifier in which the bias and input signal are adjusted so that plate current flows for the full 360° of the input cycle of signal voltage. According to the definition of class A operation, the tube or transistor could be biased at any point along its dynamic transfer characteristic, and as long as the signal is not large enough to drive the device into cutoff, it is considered a class A amplifier.

In the majority of applications of class A amplifiers, a distortion-free output is desired. To achieve this, the bias is adjusted so that

with no applied signal, the DC operating point is near the center of the linear portion of the dynamic transfer curve.

Sometimes, rf amplifiers operating as class AB are referred to as linear amplifiers in amateur radio, but this class of amplifier is not a true linear amplifier.

10-8 Draw a simple circuit diagram of each of the following and describe operation (show a signal source and include coupling and bypass capacitors, power supply connections, and plate load):

- **Audio-frequency grounded-cathode triode amplifier with resistor biasing for class A operation**
- **Audio-frequency grounded-cathode pentode amplifier with battery biasing for class A operation**
- **Radio-frequency grounded-grid triode amplifier with LC tank plate load for class B operation**

Triode Audio Amplifier with Cathode Bias Resistor. The most common method of obtaining bias in class A amplifier tubes is to incorporate a series resistor in the cathode circuit, as shown in the circuit diagram of Fig. 10-4. In this circuit the bias voltage is developed across the cathode resistor. Under quiescent conditions (the no-signal state), plate current flows continuously from cathode to plate and back to the cathode through its series resistor. Since the plate current flows from chassis ground to the cathode through the resistor, the chassis is negative with respect to the cathode.

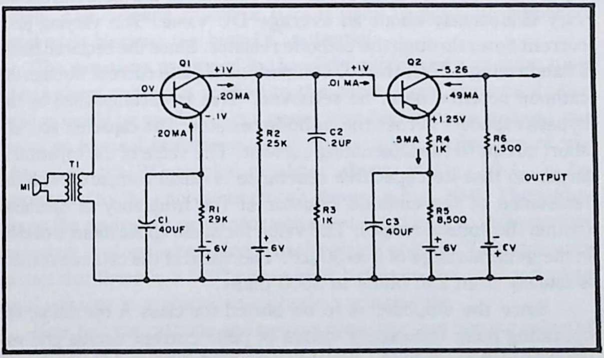


Fig. 10-3. Two-stage audio amplifiers.

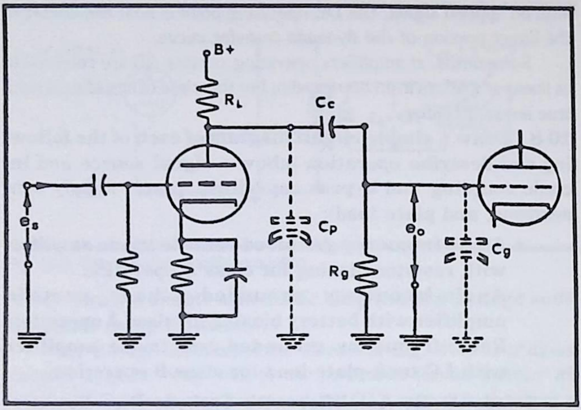


Fig. 10-4. Obtaining bias in a class A amplifier.

In Fig. 10-4, the signal source is shown by the symbol e_s. The output signal is designated e_o (as it appears at the grid of the succeeding stage). Assume that the voaltage drop across the cathode resistor is 5V. This makes the cathode 5V positive with respect to the grid (or the grid 5V negative with respect to the cathode). The grid resistor is part of the coupling network for the input signal (e_s). If the input signal is sinusoidal, the plate current will vary sinusoidally about an average DC value. The varying plate current flows through the cathode resistor. Since the required bias is a fixed voltage (5V), the AC component of plate current through the cathode resistor must be removed. This is accomplished by the bypass capacitor across the cathode resistor. The capacitor acts as a short circuit to the alternating current. The value of the capacitor is large, so that its capacitive reactance is small compared with the resistance of the cathode resistor at the frequency of operation (within the audible range). The value for audio applications would be in the general range of 0 to 50 μF. The value of the cathode resistor is usually from 250 ohms to 3000 ohms.

Since the amplifier is to be biased for class A operation, the operating point (quiescent values of plate current versus grid voltage) must be established at the center of the tube characteristic's

linear region. With an increase in the amount of negative bias, less plate current will flow; with a decrease in bias, more plate current will flow. The cathode resistor maintains a constant negative grid potential of 5V. Let us assume that when no input signal is applied to the amplifier, this 5V negative bias causes 5 mA of current to flow from cathode to plate.

The input signal is an AC waveform that rises and falls about a fixed reference point. When the signal is applied to the grid, the reference point becomes the negative 5V bias on the grid; that is, when the signal stops, the bias is at precisely 5V. As the signal goes positive, the grid bias drops below the −5V level (goes more positive); as the signal goes negative, the grid bias is increased beyond the −5V level.

The plate current, then, is a direct function of grid bias. When the grid goes slightly more negative, plate current drops considerably but in direct proportion to the negative-going grid signal. For a one-volt variation in grid voltage, the plate current may vary by, say, 10 mA.

The proportional variation in output current is passed through a resistor in the plate lead, called the load resistor (R_L). In accordance with Ohm's law, the voltage drop across a resistor changes according to the current applied to the resistor. The changing voltage here, brought about by the changing current, is the signal that is applied to the next stage. However, since this voltage is DC, it cannot be applied directly to the next stage without upsetting the next stage's biasing. The coupling capacitor (C_C) is used to pass the amplified signal while blocking the high DC potential.

The variations produced in the plate current of a vacuum tube when a signal voltage is applied to the control grid are exactly the same as would be produced in a generator developing a voltage and having an internal resistance equal to the plate resistance of the tube. Thus, the RC-coupled amplifier shown in Fig. 10-4 can be represented by the equivalent circuit shown in Fig. 10-5. The minus sign on the equivalent generator voltage is used only to indicate that the voltage is of opposite polarity to the signal voltage. This indicates the fact that there is a 180° phase shift between the grid and plate signal voltages in a grounded-cathode vacuum tube.

Note that the cathode and bypass capacitor and biasing resistor are omitted in the equivalent circuit. This omission is permissible;

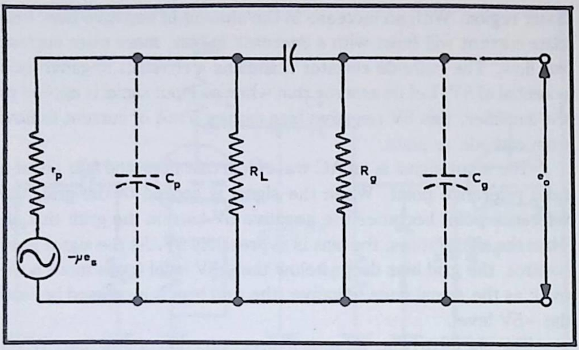


Fig. 10-5. Circuit equivalent to Fig. 10-4 but substituting generator voltage.

first, because the capacitor is of such size that it places the cathode at ground potential for AC and, second, because the biasing resistor is considered part of the plate load. All the circuit constants shown in the equivalent circuit are those that affect any ordinary triode amplifier. In fact, depending upon the frequency, some of the constants shown may be omitted. Thus, for example, in the midfrequency band (200 to 10,000 Hz) the electrode capacitances Cc and C may be omitted in equivalent circuits because their impedances are so large that they act as open circuits.

Grounded-Cathode Audio Amplifier with Battery Biasing. The circuit diagram shown in Fig. 10-6 is for a single-triode class A amplifier that obtains all its operating voltages, including grid bias, from batteries. The bias battery, in series with the signal source, is 8V, which sets the operating point for the tube. The phase and character of the input signal is described by the sine wave labeled e_c. The varying plate current in the output is labeled i_b. The plate load resistor signal is labeled e_{RL}. The output signal, 180° out of phase with the input, is labeled e_b(out).

Assume that the tirode shown in the figure is a 6J5 tube with operating voltages as illustrated (−8V grid bias and 350V plate supply potential). Under no-signal conditions, the plate current is 5.2 mA, and plate voltage is 220V. The load resistor is 25K. The voltage drop across the load resistor under no-signal conditions is the supply voltage minus the plate voltage, 350V − 220V, or 130V. The vari-

ous voltages and currents appearing in the triode circuit are shown graphically in Fig. 10-7. The waveshapes shown are obtained in the following manner: Points A, A1, A2, A3, and A4, connected by a vertical dotted line, represent conditions which occur at quiescence, or with no signal. The signal voltage (in graph A) is zero at point A, and the total grid voltage (in B) equals −8V at point A1, which is the value of bias. At the same time, the total plate current, in graph C, equals 5.2 mA at point A2. The DC voltage drop across the load resistor (referred to the graph as E_{LO}) in D, equals 130V at point A3. The total plate voltage, in graph E, is equal to 220V at point A4.

When the grid signal voltage reaches its most positive value at point B, the total grid voltage (e_c) is zero volts at point B1. The maximum signal voltage on the grid causes the plate current to rise to a maximum value of 10.1 mA at point B2. This maximum current causes the voltage drop across the load resistor to be a maximum value of 252V at point B3. The load resistor R_L, plate resistance r_p and plate supply E_{bb} comprise a series circuit. The voltage drops across R_L and r_p equal the supply source voltage. If the voltage drop across R_L increases, the voltage drop across r_p must decrease. The output voltage from plate to cathode is the voltage drop across r_p. Since the voltage drop across R_L is at a maximum at point B3, voltage is at a minimum. This is shown at point B4, which equals 98V.

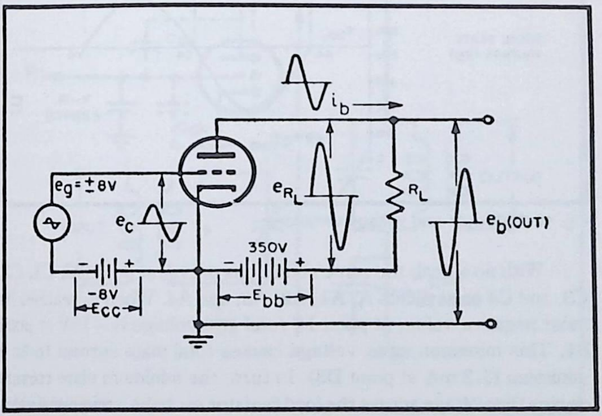


Fig. 10-6. Single-triode class A amplifier circuit.

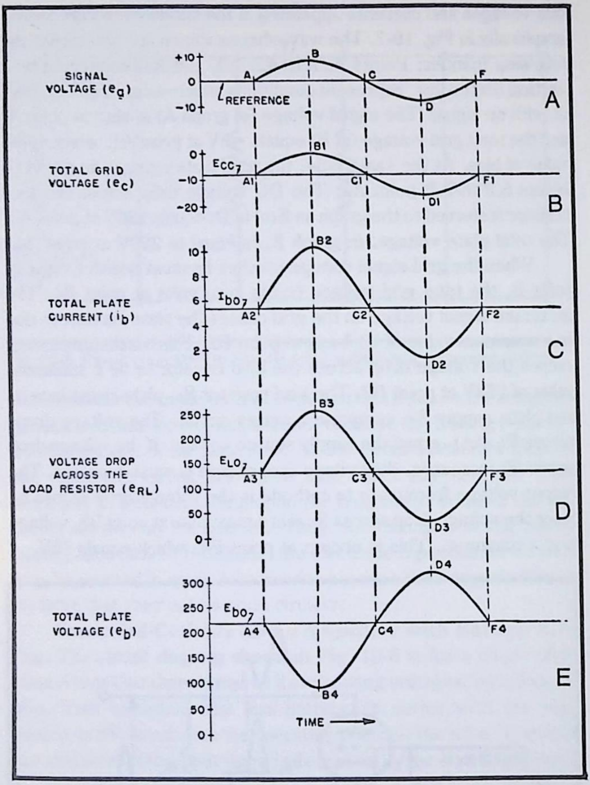


Fig. 10-7. Current and voltage variations.

With no signal, the same conditions prevail at points C, C1, C2, C3, and C4 as at points A, A1, A2, A3, and A4. When e_g reaches its most negative value, at point D, total grid voltage is −16V at point B1. This minimum input voltage causes total plate current to be a minimum (1.3 mA at point D3). In turn, the minimum plate current causes the voltage across the load resistor e_{RL} to be a minimum value of 33V at point D3. Since the voltage across R_L is a minimum, the

voltage drop across r_p is a maximum and total plate voltage e_b is a maximum (317V at D4). Points F, F1, F2, F3, and F4 occur at no-signal and have the same numerical values at the corresponding points C, C1, C2, C3, and C4.

From the foregoing analysis it is noted that the waveshapes shown in graphs A, B, C, and D are in phase with each other but are 180° out of phase with waveshape E.

Consequently, the following conclusion can be made: The signal on the control grid of an electron tube is always in phase with the plate current but is 180° out of phase with the output plate voltage. This statement holds true for all types of electron tubes, whether they are triodes, tetrodes, or pentodes.

Class B Grounded-Grid RF Triode Amplifier with LC Tank Plate Load. In the grounded-grid amplifier (Fig. 10-8) the signal is applied between the cathode and ground, the grid is grounded, and the output is taken across a load between plate and ground—in this case, the LC tank plate load.

The grounded-grid circuit permits a triode to be operated at high frequencies without the need for neutralization. Therefore, one of the most objectionable drawbacks of a triode rf power amplifier is

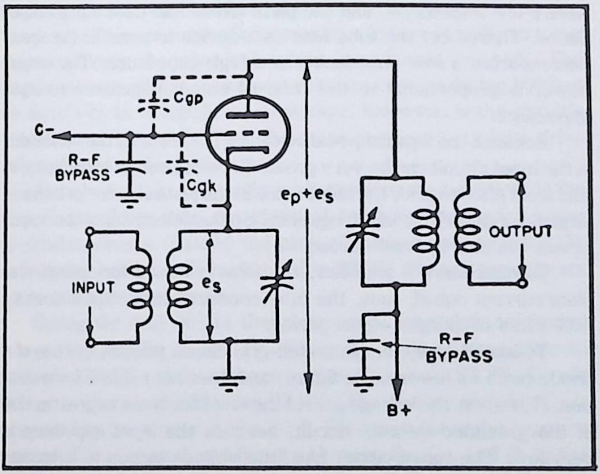


Fig. 10-8. Grounded-grid amplifier circuit.

overcome. In this circuit the grid is grounded through an rf bypass capacitor and serves as a shield between the input and the output circuits, thus preventing feedback of energy and resultant oscillation. It also has the advantage of very low output capacitance, since the only capacitance across the output added by the tube is that between grid and plate (Fig. 10-8). In tubes designed especially for this purpose, the capacitance is made very low, and large values of inductance may be used in the plate circuit at relatively high frequencies. This results in higher efficiency.

Another characteristic of the grounded-grid amplifier is that both the driver stage (which supplies the input) and the amplifier stage itself supply the plate load circuit. The driver stage produces an rf voltage across the input terminals. An rf voltage also is produced across the plate and cathode elements of the tube. These voltages are 180° out of phase in respect to the cathode, and therefore the rf output voltage from plate to ground is the sum of the two out-of-phase voltages.

The plate current generally is 180° out of phase with the plate voltage; this means that the signal current flowing in the cathode circuit must be the same as the plate current. The cathode can now have a low impedance, and the plate circuit can have a high impedance. Therefore, the tube acts as a device to transfer the space current from a low impedance to a high impedance. The output power is proportional to the ratio of output impedance to input impedance.

Because the input impedance can be made small, the bandwidth in the input circuit can be very great. Since the output capacitance is that from plate to grid, the inductance in the plate circuit can be made large for a given resonant frequency. So the selectivity of the output circuit can also be made broad.

Being a class B amplifier, the tube is biased for operation at plate current cutoff; thus, the tube conducts during approximately 50% of its total input signal period.

To summarize, the grounded-grid circuit permits the use of a triode (with its lower noise figure) and does not require neutralization. However, the voltage gain of the amplifier is not as great as that of the grounded-cathode circuit, because the input impedance is very low. The tuned circuit has little voltage stepup to overcome tube noise, and the overall noise performance tends to suffer some-

what. The low-impedance input circuit permits the attainment of wide bandwidth and a reasonable noise figure without sacrificing too much voltage gain in the input circuit. The gain of the grounded-grid amplifier may not be great enough to override the noise produced by some converter tubes; thus, it is common practice to find two grounded-grid amplifiers in cascade. The added complications arising from this necessity and the need for special tubes limit its use. The tubes themselves must have very low effective plate-to-cathode capacitance if the shielding effect of the grounded grid is to be realized.

10-9 Draw circuit diagrams and explain the operation (including input and output phase relationships, approximate practical voltage gain, approximate stage efficiency, uses, advantages, and limitations) of the following types of audio circuits:

- **Class A amplifier with cathode resistor biasing**
- **Cathode follower amplifier wih grounded plate**

Cathode-Biased Class A Amplifier. A cathode-biased class A amplifier is shown in Fig. 10-9. Note that input and output signal polarities (phase relationships) are shown in the accompanying waveforms. This is a conventional amplifier for use in audio circuits; characteristically, its input and output impedances are high. The stage is not very efficient because it requires current during 100% of the signal's cycle. A significant advantage, however, is the circuit's freedom from distortion. Also, the stage requires very little drive and provides excellent gain.

At the beginning of the positive alternation, the conditions in the plate circuit of the tube are identical to those that exist under no-signal conditions. That is, the plate-to-ground voltage is 93.2V, and coupling capacitor C_C is charged to 93.2V. No voltage appears across grid-leak resistor R_G.

During the first 90° of the plate signal, the plate-to-ground voltage rises rapidly to 127.1V. Since the voltage from plate to ground is 127.1V and the voltage across C_C is only 93.2V, C_C will attempt to charge an additional 33.9V. The charge path for C_C is designated by the arrows in Fig. 10-9. Electrons leave the negative terminal of E_{BB} (ground) and flow up through R_G, C_C, and R_L to the positive terminal of E_{BB} (B+), and then through E_{BB}, completing the

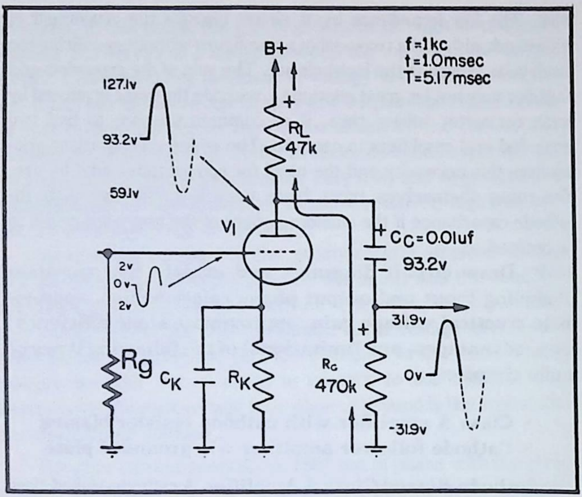


Fig. 10-9. Cathode-biased class A amplifier circuit.

circuit. Note that, in charging, the displacement current of Cc must flow through RL and RG.

Since the series resistance is large, the time constant for charge is long compared to the period of the sine wave being amplified. The charge time constant of the coupling capacitor is 5.17 msec. A 1 kHz sine wave has a period of 1 msec; therefore, the first 90° of the plate signal requires 0.25 msec. In this brief time (5% of one time constant), the capacitor can only begin to charge to the new value of plate voltage. This short period limits the charging of the capacitor during the first 90° of the signal to about 6% of the available increase of 33.9V, or to an actual increase of about 2V.

In brief, the single-ended class A stage shown in Fig. 10-9 has these characteristics:

1. It is a phase inverter; that is, the output is always a mirror image of the input.
2. The voltage gain is quite high—considerably better than grounded-grid and grounded-plate circuits.
3. The approximate stage efficiency is 20% or less.

4. Circuits of this type once were accepted as standards for audio amplification, and can be found in obsolete stereo systems, tape recorders, and radios. The phase-inversion phenomenon has also made the circuit useful in applications where a polarity reversal of the input signal is desirable.

Cathode Follower Amplifier. The cathode follower circuit is shown in Fig. 10-10. Until the advent of the transistor, the cathode follower was one of the most useful and common of the basic audio circuits.

To achieve uniform response over a wide frequency range, an amplifier should have a low effective input capacitance and a low effective load impedance. The overall response may also be improved by the use of degenerative feedback. The cathode follower possesses these qualities and, in addition, it may be used to match the impedance of one circuit to that of another.

The cathode follower is a single-stage class A degenerative amplifier, the output of which appears across the unbypassed cathode resistor. The high input impedance (no grid current) and the low output impedance make it expecially useful for matching a

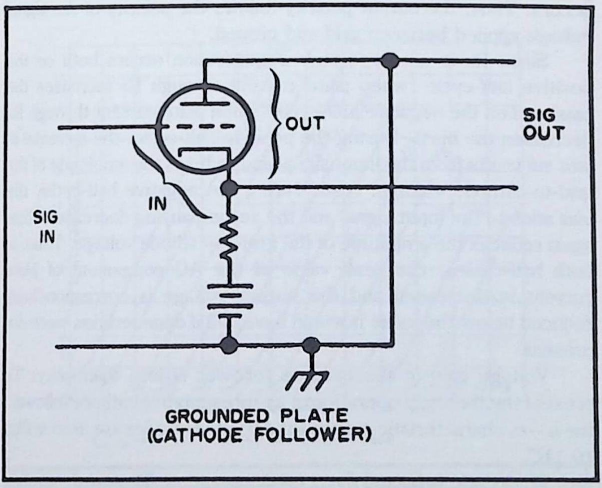


Fig. 10-10. Cathode follower circuit.

high-impedance source to a low-impedance load. Thus, the cathode follower might be used between a pulse-generating stage and a transmission line whose effective shunt capacitance might be great enough to cause objectionable effects. More power, of course, can be delivered when the source is matched to the load. For example, a conventional amplifier having high output impedance would supply less power to a low-impedance coaxial line than would a cathode follower having an output impedance that corresponds to the load impedance.

The advantages obtained by use of a cathode follower can be had only at the price of a voltage gain that is less than unity. However, the circuit is capable of producing power gain.

A conventional cathode follower is shown along with its characteristics in Fig. 10-11A. Under no-signal condition a certain amount of plate current flows through R_K, and this flow establishes the normal bias. When a positive-going signal is applied to the grid, the plate current increases. This increase causes a rise in the voltage drop across R_K, giving the cathode a higher positive potential with respect to ground than it had under the no-signal condition. When a negative-going signal is applied to the grid, the opposite effect occurs. Thus, the output polarity follows the polarity of the signal voltage applied between grid and ground.

Since R_K is not bypassed, degeneration occurs both on the positive half-cycle (when plate current through R_K increases the bias) and on the negative half-cycle (when plate current through R_K decreases the bias). During the positive half-cycle, the increase in bias subtracts from the input signal and reduces the amplitude of the grid-to-cathode voltage. Also, during the negative half-cycle, the bias adds to the input signal and the accompanying decrease in bias again reduces the amplitude of the grid-to-cathode voltage. Thus, in both half-cycles, the peak value of the AC component of plate current is decreased and the output voltage is correspondingly reduced below the value it would have had if degeneration were not present.

Voltage gain in the cathode follower is less than unity. To present the theory of operation of a representative cathode follower, the $i_p - e_p$ characteristic curves for a triode amplifier are used in Fig. 10-11C.

The triode is biased for class A operation. The no-signal plate current is 0.008A, the no-signal plate voltage is 200V, and the grid

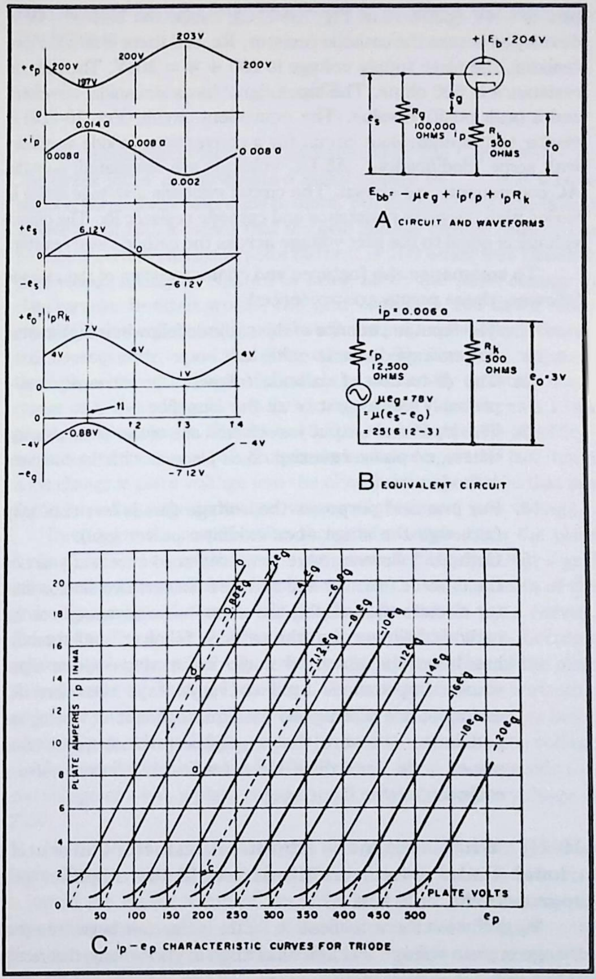


Fig. 10-11. Conventional cathode follower with characteristics curves (A); equivalent circuit (B); characteristic curves for triodes (C).

bias is −4V (point A of Fig. 10-11C). Since the bias of −4V is developed across the cathode resistor, R_K, and there is no plate load resistor, the plate supply voltage is 200 + 4 = 204V. The cathode resistance is 500 ohms. The input signal has a sinusoidal waveform and a peak positive value. The equivalent circuit (Fig. 10-11B) is similar to the equivalent circuit for a conventional triode amplifier, with some modifications. All DC voltages are eliminated; only the AC components are shown. The circuit contains a voltage acting in series with the plate resistance and cathode resistor R_K. The output voltage is equal to the i_pR_K voltage across the cathode load resistor.

To summarize the features and characteristics of the cathode follower, these points are presented:

1. The input impedance of the cathode follower is high and the output impedance is quite low.
2. The distortion of cathode followers is extremely low—probably the lowest of all the amplifier types.
3. The input and output waveforms are of the same polarity; that is, no phase reversal takes place as with the common-cathode circuit.
4. For practical purposes the voltage gain is less than unity (although the stage does exhibit a power gain).
5. Cathode followers have been replaced in recent years by the emitter follower and source follower, two semiconductor circuits that exhibit the same basic advantages as the cathode follower; but the cathode follower, until recently, has been the standard audio input stage where signal source impedances tend to vary. Tape recorders, for example, are often used with microphones of varying impedances; to insure that a good impedance match takes place, good recorders have traditionally incorporated a cathode follwer input stage.

10-10 What is meant by amplification factor (mu or μ) of a triode? Under what conditions would the amplifier gain approach the value of μ?

By definition the amplification factor is the ratio between a small change in plate voltage and a small change in grid voltage that results in the same change in plate current. It is an indication of the effectiveness of the control grid voltage relative to the plate voltage in

controlling the plate current. Expressed as a formula, the amplification factor is

$$\mu = \frac{\Delta e_b}{\Delta e_g}$$

The amplification factor is represented by the Greek letter μ. The Greek letter Δ represents *a small change in . . .* It is a pure number, without any reference to units. For example, if a tube is said to have a μ of 100, it means that the grid voltage change required to produce a certain change in plate current is 100 times less than the plate voltage changes required to bring about the same change in plate current. In other words, the grid voltage is 100 times more effective than the plate voltage in its influence upon the space charge and, consequently, upon the plate current. To illustrate, suppose that a plate current change of 1 mA is produced by a plate voltage change of 10V, and a grid voltage change of 0.1V produces a 1 mA change in plate current. Then μ is 10/0.1, or 100; and the amplification factor, of course, is 100. Emphasis is placed upon the fact that it is the change in plate voltage and the change in grid voltage that are important and not the individual values of plate and grid voltage.

Developing the amplification factor of a triode from the plate family of curves is a relatively simple process. Simply select a grid voltage value that is about halfway between the usable limits of the grid voltage range shown on the graph of the tube's plate curves. Referring to Fig. 10-12, −8V is a satisfactory grid voltage. Locate a reference point about halfway down the straight portion of the plate current curve for that grid voltage. This is point A. A horizontal projection parallel to the plate voltage axis shows point A as being equal to 5 mA. A vertical projection (downward to the plate voltage scale) shows A to be equal to 216V. Point A, then corresponds to a grid voltage of −8V, a plate current of 5 mA, and a plate voltage of 216V.

Now, project point A along the X-axis to an adjacent grid bias curve. The direction of this projection is optional. In this instance, it is toward the higher value of negative grid bias. This is point B, where the grid voltage is −10V. A vertical projection dropped to the plate voltage axis intersects the 257V point. Point B can therefore be described as follows: grid voltage, −10V; plate current, 5 mA; plate voltage, 257V.

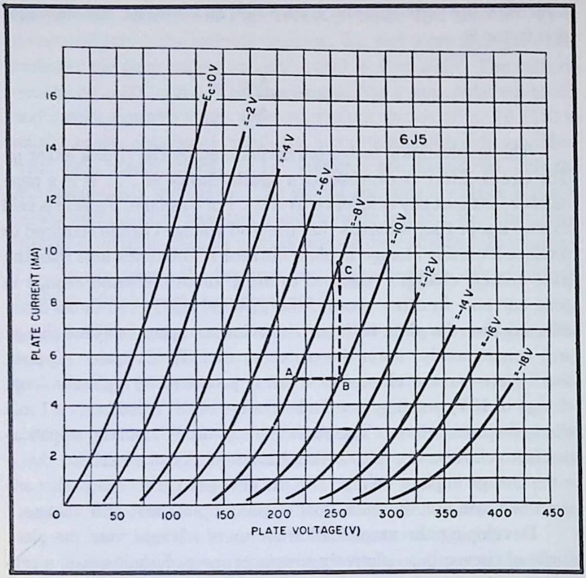


Fig. 10-12. Tube plate curves.

The next step is to project the higher plate voltage point on the $-8V$ curve; this results in point C. Point C corresponds to a grid voltage of $-9V$, a plate current of 9.6 mA, and a plate voltage of 257V. The information needed to calculate μ has been obtained. With 216V on the plate (point C), a change in plate current from 5 to 9.6 mA takes place. With 257V on the plate, a change in grid voltage from $-10V$ (point B) to $-8V$ (point C) causes a change in plate current from 5 to 9.6 mA. Therefore, the equation is

$$\frac{257 - 216}{10 - 8} = \frac{41}{2} = 20.5$$

The value of μ is realized with very high plate load resistance values when the load impedance in the plate circuit is many times the value of the tube's plate resistance.

10-11 What is meant by plate current saturation?

Plate current saturation is the point in an amplifier's operating curve where further increases in grid voltage do not result in appreciable increases in plate current, regardless of the plate voltage. At this point, the plate resistance of the electron tube is essentially zero. In the triode amplifier load line of Fig. 10-13, saturation is indicated at point A on the graph. The opposite end of the line, point B, is the cutoff point. Audio amplifiers are operated in the linear region between the two extremes.

10-12 What is meant by "load" on a vacuum tube? What is a "load line"?

The load is the series resistance in the plate circuit. In Fig. 10-13 the load on the tube is the resistance labeled R_L. The load is the factor that determines the operating conditions of the tube and is the prime means by which amplifier operation can be analyzed. The straight line drawn across the voltage-current curves is called the *load line*. It is the result of plotting the values of plate current and plate voltage in the triode circuit and connecting all of the plotted points by a straight line. One extremity of the load line is the point where the plate current is zero and the voltage drop across the load is zero. The other extreme is the point where the plate current is absolutely unlimited by the tube—that is, the tube acts as a short circuit. Current at this point is limited only by the load and may be calculated using Ohm's law. When the tube is shorted, plate voltage is zero. The slope of the load line is determined by the load itself. The greater the load, the less the slope. The load line and the curves in Fig. 10-13 are based on the triode circuit shown.

10-13 What are the factors that determine the correct bias voltage for the grid of a vacuum tube?

In an audio amplifier the bias is chosen so that the tube operates as closely as possible to the center of its linear transfer characteristic. The bias point must be chosen so that no amount of input signal will cause the grid circuit to draw current. In a class B amplifier such as the type used in push-pull audio amplifiers, each tube must be made to operate (during the no-signal state) near cutoff, which is at the lower limit of the tube's linear region.

A positive control-grid voltage results in the presence of grid current between the grid and cathode through the system external to the tube. This condition cannot be avoided, because the grid wires

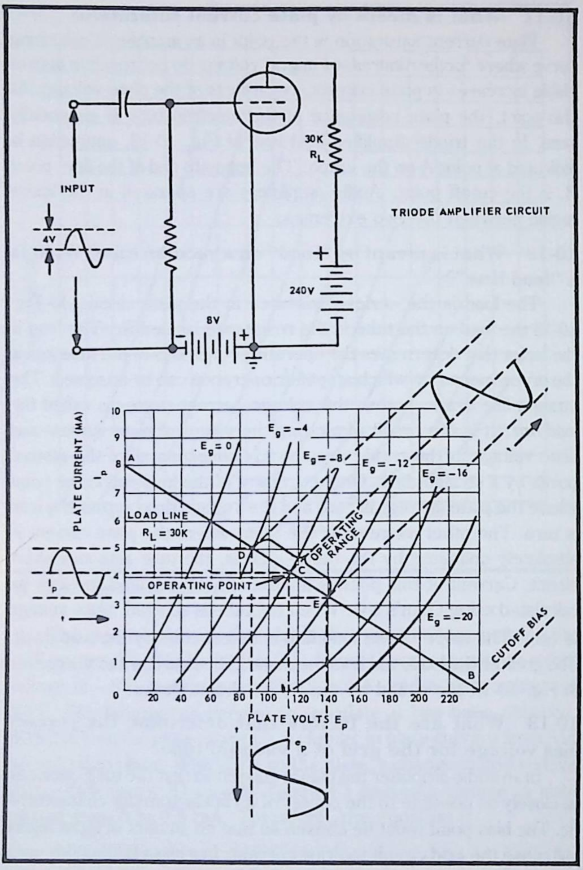


Fig. 10-13. Triode amplifier circuit with performance characteristics.

intercept electrons that are advancing toward the grid on their way to the plate. The positively charged grid attracts electrons into itself. Disregarding, for the moment, any applications that permit grid current to flow, the presence of grid current is normally undesirable.

It represents the needless comsumption of power and other unwanted effects.

The signal voltage normally applied to a control grid is alternating; at least it is a voltage that varies in amplitude and, perhaps, in polarity relative to the cathode. During the time that it is negative with respect to the cathode, freedom from grid current is obvious. But when it is positive, grid current is present unless some means is provided to keep the control grid at a negative potential during the positive portion of the input signal. The purpose of the negative grid bias is to establish this operating condition. Bias may be defined as the DC voltage between the grid and the cathode. It is represented by battery C in Fig. 10-14. The total voltage existing between grid and cathode is the signal voltage plus the bias voltage.

The association between the signal and the grid bias is illustrated in Fig. 10-15. Curve A represents an input AC signal of 5V peak. It varies between 5V positive and 5V negative. To keep the control grid negative during the entire positive alternation of the input signal, the grid bias must equal if not exceed the peak value of the signal. Thus, the control grid bias is arbitrarily set at –6V, as in curve B. Since the grid is negative with respect to the zero-voltage reference level it is shown below the reference voltage line.

The resultant of the signal and bias voltages at the control grid, instant by instant, is shown as curve C in the same illustration. Curve C is the addition of curves A and B. The fixed bias voltage sets up the initial voltage relationship between the control grid and cathode. This is the no-signal condition (as in curve B). It is represented by 1 to 2 and 8 to 9 in curve A, and 1' to 2' and 8' to 9' in curve C. The times from 1 to 2 and 8 to 9 in curve A represent the period of zero

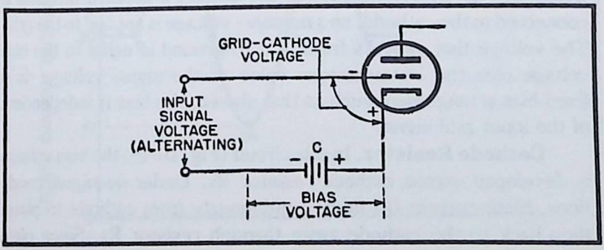


Fig. 10-14. Bias voltage representation.

signal voltage, during which time the full −6V of grid bias is active on the control grid, as shown in times 1' to 2' and 8' to 9' in curve C.

As the signal voltage starts rising in the positive direction (from 2 to 3) it bucks the fixed negative bias, and the control grid becomes less and less negative until, at the peak of the positive alternation of the signal voltage (point 3), the control grid is one volt negative with respect to the cathode, as shown by 3' in curve C. As the signal voltage decreases in positive amplitude (from 3 to 4 in curve A), more and more of the bias voltage becomes predominant, until point 4 is reached, which again corresponds to zero signal voltage. The control grid again becomes 6V negative with respect to the cathode, as shown by point 4' on curve C. Examining the action during the positive half-cycle of the applied signal voltage, points 2' to 4' in curve C, it is evident that a 0.5V change in signal voltage in the positive direction has taken place at the control grid, but the grid electrode remains negative throughout the half-cycle.

During the negative alternation of the signal voltage (points 4 to 6), the signal and the fixed negative bias voltages add. The result is a change in voltage at the grid from −6V (4′ in curve C) to maximum negative voltage of −11V (5′), and then a return to −6V (6′) again. The control grid remains negative with respect to the cathode by an amount equal to the sum of the instantaneous signal voltage and the fixed grid bias.

10-14 Draw schematics illustrating the following types of grid biasing and explain their operation: battery, cathode resistor, power supply, voltage divider.

Battery. Bias is the DC voltage applied between grid and cathode of a vacuum tube. A battery (C) that supplies this bias is shown in Fig. 10-14. As shown, the battery's positive terminal is connected to the cathode, so a negative voltage is applied to the grid. The voltage that appears from grid to ground is equal to the bias voltage plus the instantaneous value of the signal voltage. In a fixed-bias arrangement such as that shown, the bias is independent of the input grid signal.

Cathode Resistor. In this circuit (Fig. 10-16) the bias voltage is developed across cathode resistor R_K. Under *no-signal* conditions, plate current (i_b) flows continuously from cathode to plate, then back to the cathode again through resistor R_K. Since plate current flows from point A to point B, point A is negative with

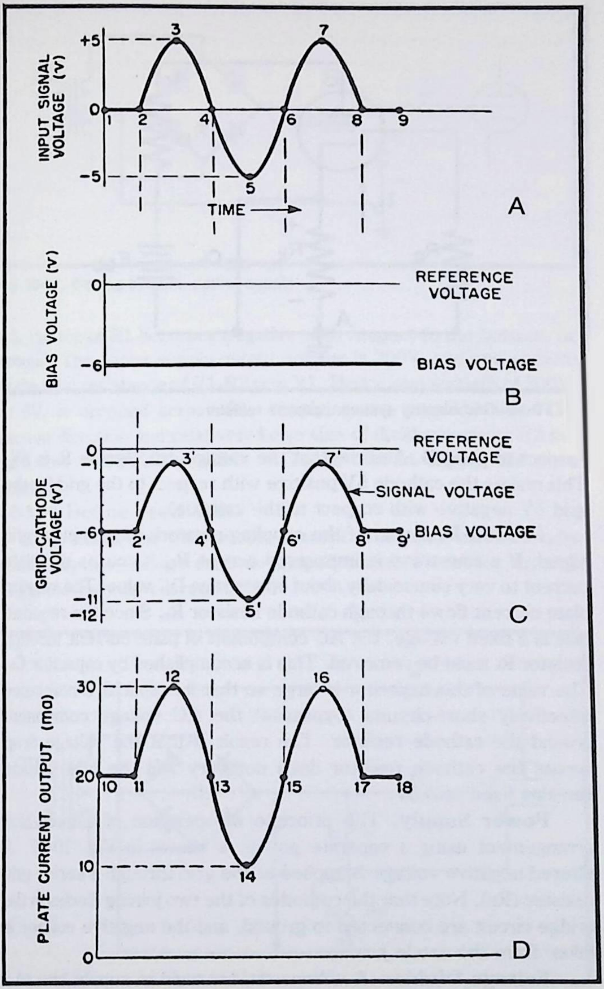


Fig. 10-15. Signal and grid bias associations.

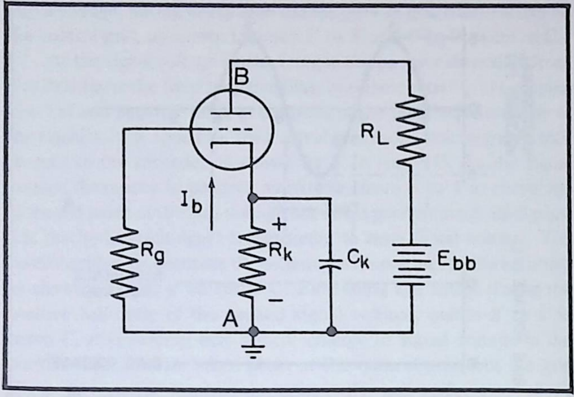


Fig. 10-16. Grid biasing system, cathode resistor.

respect to point B. Assume that the voltage drop across R_k is 5V. This makes the cathode 5V positive with respect to the grid (or the grid 5V negative with respect to the cathode).

Resistor R_g is part of the coupling network for the input grid signal. If a sine wave is impressed across R_g, it causes the plate current to vary sinusoidally about an average DC value. The varying plate current flows through cathode resistor R_k. Since the required bias is a fixed voltage, the AC component of plate current through resistor R_k must be removed. This is accomplished by capacitor C_k. The value of this capacitor is large so that its capacitive reactance effectively short-circuits (bypasses) the AC voltage component around the cathode resistor. The result is that the voltage drop across the cathode resistor does not vary and the bias voltage remains fixed at −5V.

Power Supply. The principle of operation of a fixed-bias arrangement using a separate power is shown in Fig. 10-17. A filtered negative voltage is applied to the grid through a series grid resistor (R_G). Note that the cathodes of the two joining diodes in the bridge circuit are connected to ground, and the negative voltage is taken from the anode junction.

Voltage Divider. A voltage divider used to supply bias to a tube is shown in Fig. 10-18. As electrons flow down through R1 and

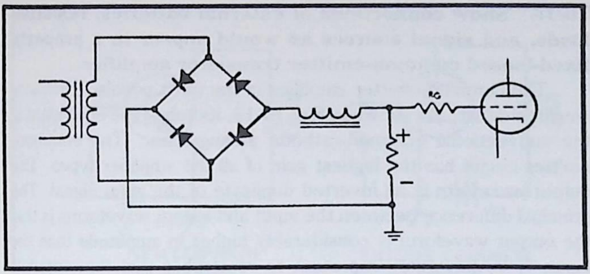


Fig. 10-17. Biasing system, power supply.

R2, the top of R1 becomes negative with respect to the bottom, or ground. The power supply output voltage is 300V, and one-sixtieth of the total resistance of R1-R2 is in R1. Hence one-sixtieth of 300V, or 5V, is dropped across R1, supplying the required bias. The current direction and relatively large size of divider resistor R2 are such that +295V is available at its bottom to supply the plate potential.

10-15 Define "self bias."

Self bias is the bias on the control grid of an electron tube created by the voltage drop developed across a resistor through which the cathode current flows.

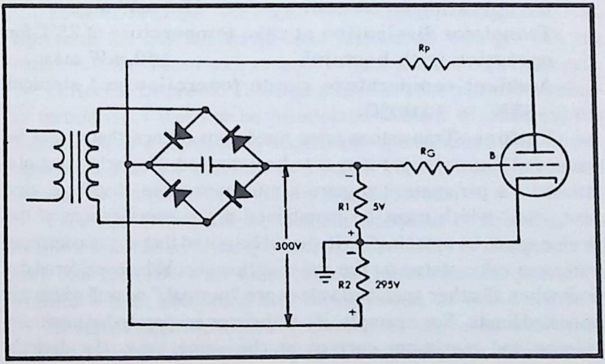


Fig. 10-18. Biasing system, voltage divider.

10-16 Show connections of external batteries, resistive loads, and signal sources as would appear in a properly fixed-biased common-emitter transistor amplifier.

The common-emitter amplifier is the most popular transistor amplifier cirucit. As shown in Fig. 10-19, its tube-type equivalent is the conventional common-cathode arrangement. The common-emitter circuit has the highest gain of all the amplifier types. The output waveform is an inverted duplicate of the input signal. The principal difference between the input and output waveforms is that the output waveform is considerably higher in amplitude than the input. It is, however, important to remember that the output is shifted in phase from the input by precisely 180°.

10-17 The following are excerpts from a transistor handbook describing the characteristics of a pnp alloy-type transistor as used in a common-emitter circuit. Explain the significance of each item.

Collector-to-base voltage (emitter open) . . . . −40V max
Collector-to-emitter voltage (base-to-emitter voltage = 0.5V) . . −40V
Emitter-to-base voltage . . . −0.5V max
Collector current . . . . 10 mA max
Transistor dissipation at ambient temperature of 25°C for operation in free air . . . . . . 120 mW max
Transistor dissipation at case temperature of 25°C for operation with heatsink . . . . 140 mW max
Ambient temperature range (operation and storage) −65°C to +100°C

Ratings. Transistors have maximum ratings that cannot be exceeded if normal operation is to be expected. Similarly, many of a transistor's parameters require a minimum value of voltage, current, etc., which must be maintained if the specifications of the device are to be meaningful. It should be noted that any maximum or minimum value stated on the specification should be considered the limit when all other specified values are "normal," or well within the specified limits. For example, if a transistor is operated at maximum voltage and maximum current at the same time, the device's maximum power dissipation capability will probably be exceeded.

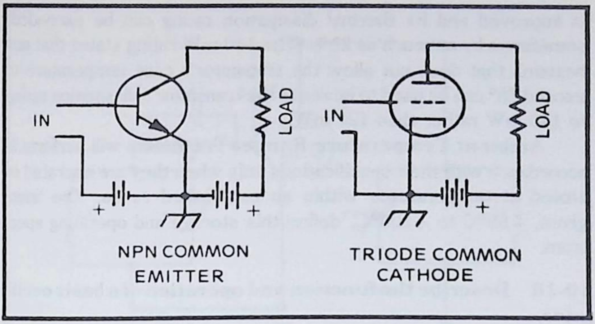


Fig. 10-19. Common emitter amplifier (left) and tube-type equivalent.

Open-Emitter Collector Voltage. This voltage, designated as V_{cbo}, is the maximum voltage that can be applied between the base and collector without exceeding the collector-base junction breakdown point. Here, the base is considered to be reverse-biased (−40V), and the emitter is open.

Collector-to-Emitter Voltage. This voltage, designated V_{ce}, is the DC collector-to-emitter breakdown voltage when the collector is reverse-biased with respect to the emitter and the emitter junction is reverse-biased through a specified circuit by 0.5V.

Emitter-to-Base Voltage. This voltage, designated V_{ebo}, represents the DC emitter-to-base breakdown voltage with the emitter reverse-biased with respect to base and the collector open.

Collector Current. This rating specifies the maximum collector current (DC) that can be maintained without overheating the transistor. It is a particularly significant specification with power transistors. The low collector current of 10 mA would mean the transistor is restricted to small-signal applications.

Free Air Dissipation. Without adequate heatsinking, the transistor referred to in the question has the ability of dissipating no more than 120 mW. With some external means for dissipating the transistor's heat, this rating may be exceeded, as noted below.

Heatsinking. Most power transistors are used with some external device designed to carry heat away from the semiconductor. When such an additional heatsink is used, the device's efficiency

is improved and its thermal dissipation rating can be exceeded, sometimes by as much as 25%. The 140 mW rating states that any heatsink that does not allow the transistor's case temperature to exceed 25° can be used to increase the transistor's dissipation rating to 140 mW rather than 120 mW.

Ambient Temperature Range. Transistors will perform in accordance with their specifications only when they are operated or stored at temperatures within an established range. The limits given, −65°C to +100°C, define this storage and operating spectrum.

10-18 Describe the function and operation of a basic oscillator.

The primary function of an oscillator is to generate a given waveform at a constant amplitude and specific frequency, and maintain this waveform within certain limits. An oscillator is a group of electronic components which, when supplied with a source of energy in the proper phase and of sufficient amplitude to overcome circuit losses, will furnish an electrical periodic function repetitively. Since transistors and electron tubes are amplifiers, they may be used in oscillator circuits to provide the energy required.

A basic oscillator can be broken down into three main sections. The frequency determining device is usually an LC tank circuit. While the tank circuit is normally found in the input circuit of the oscillator (both transistor and electron tube), it should not be considered out of the ordinary if it appears in the output circuit of a transistor oscillator. The differences in magnitude of collector and plate currents and shunting impedances are partly responsible for

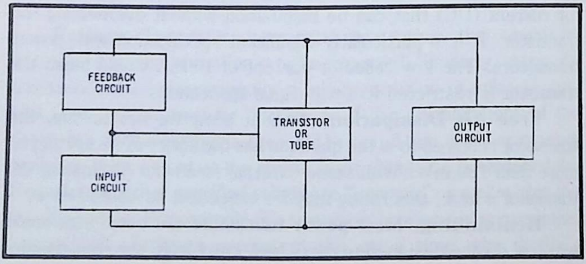


Fig. 10-20. Basic oscillator block diagram.

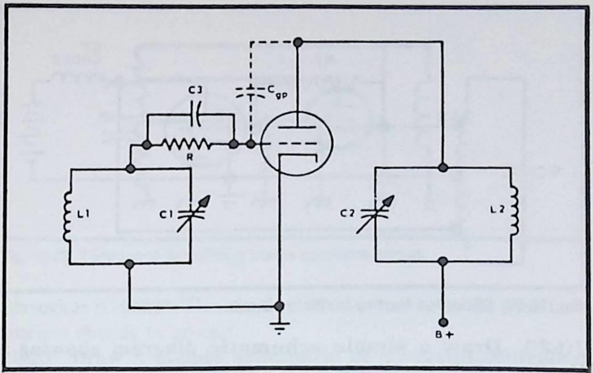


Fig. 10-21. TPTG oscillator circuit.

this. In both types of circuits (solid state and tube) oscillations tak place in the tuned circuit.

Both the transistor and tube function primarily as an electric valve that amplifies and allows the feedback network to automatically deliver the proper amount of energy to the input circuit to sustain oscillations. In both transistor and tube oscillators the feedback circuit couples energy of the proper amount and phase from the output to the input circuit in order to sustain oscillations. A basic block diagram is shown in Fig. 10-20. The circuit is essentially a closed loop utilizing DC power to maintain AC oscillations. Oscillators differ mainly in the type and method of feedback used.

10-19 Draw a simple schematic diagram showing a tuned-plate, tuned-grid (TPTG) oscillator with a series-fed plate, indicating the polarity of all applied voltages.

Refer to Fig. 10-21. This oscillator has tuned circuits in both grid and plate circuits, and it is advantageous because it may be used equally well at low as well as ultrahigh frequencies. Notice in the figure that the inductance in the plate tank circuit is not inductively coupled to the inductance in the grid circuit. The feedback to sustain oscillation occurs through the interelectrode capacitance of the tube from grid to plate; this is illustrated by a broken line showing the grid-to-plate capacitance (C_{gp}) inherent in the tube.

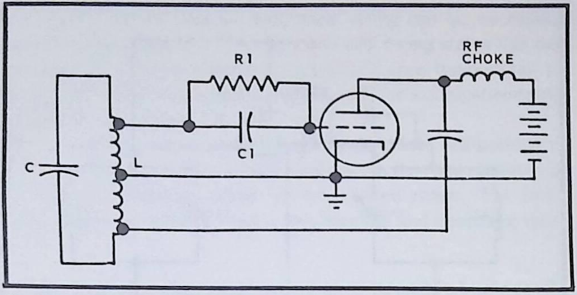


Fig. 10-22. Shunt-fed Hartley oscillator circuit.

10-20 Draw a simple schematic diagram showing a Hartley triode oscillator with a shunt-fed plate, indicating voltage polarities.

In the shunt-fed Hartley oscillator (Fig. 10-22) direct current does not flow through any part of the tank circuit, and the plate supply voltage is in parallel with the tube and tank circuit. An rf choke keeps radio-frequency signals out of the plate supply, and DC is kept out of the tank circuit by a blocking capacitor.

10-21 Draw a simple schematic diagram showing a tuned-grid Armstrong triode oscillator with a shunt-fed plate, indicating voltage polarities.

The Armstrong oscillator is perhaps the oldest of all oscillators. You can recognize it easily by the "tickler" winding it incorporates to introduce feedback. In the circuit pictured in Fig. 10-23, B+ voltage is applied through an rf choke to the plate. Varying the number of turns in the tickler winding adjusts the feedback fraction. Questions on the Armstrong oscillator often show up on FCC tests in spite of the fact that the vacuum-tube version is virtually obsolete and even the transistor equivalent is rarely seen.

10-22 Draw a simple schematic diagram showing a tuned-plate, tuned-grid oscillator (triode) with shunt-fed plate.

The shunt-fed TPTG oscillator looks very similar to the series-fed unit. As shown in Fig. 10-24, the only difference is that the shunt-fed type receives its plate voltage directly from the source

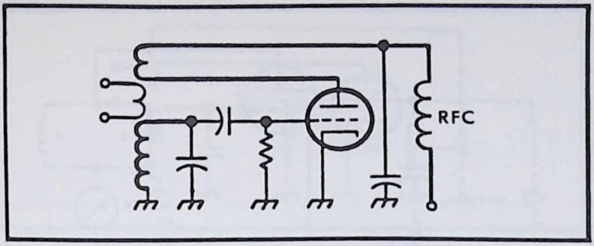


Fig. 10-23. Tuned-grid Armstrong triode oscillator circuit.

(through an rf choke). The tuned circuit that makes up the plate tank connects directly to ground.

10-23 Draw a simple schematic of a crystal-controlled tube-type oscillator.

Since a quartz crystal is equivalent to a resonant circuit, it can be used in place of the usual tuned circuit as a frequency-controlling element in an oscillator. The circuit shown in Fig. 10-25 is a common triode oscillator using a quartz crystal.

10-24 Draw a simple schematic diagram showing a Colpitts oscillator (triode) with a shunt-fed plate.

The Colpitts oscillator is essentially the same as the Hartley, except that a pair of capacitances in series is connected across the

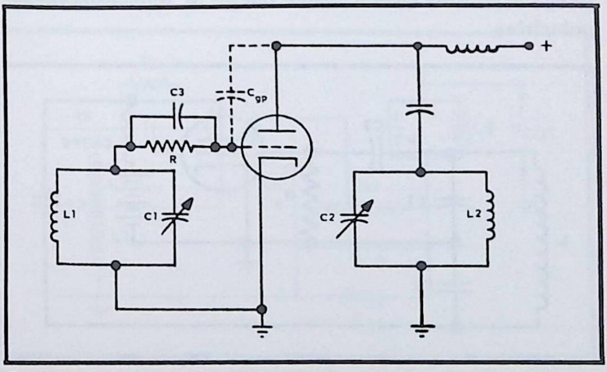


Fig. 10-24. Shunt-fed TPTG oscillator circuit.

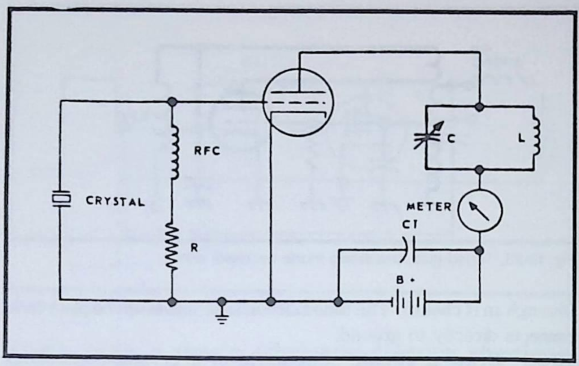


Fig. 10-25. Crystal-controlled tube-type oscillator circuit.

tank coil. The capacitive combination of C1 and C2 in Fig. 10-26 forms a voltage divider that splits the potential across the resonant circuit. The voltages at the ends of the resonant circuit are opposite in polarity with respect to the cathode and in the right phase to sustain oscillation. Total tank capacitance consists of C1 and C2; the grid-leak bias combination is made up of C3 and R_g.

10-25 Draw a simple diagram of a tuned-grid Armstrong triode oscillator with a series-fed plate, indicating voltage polarities.

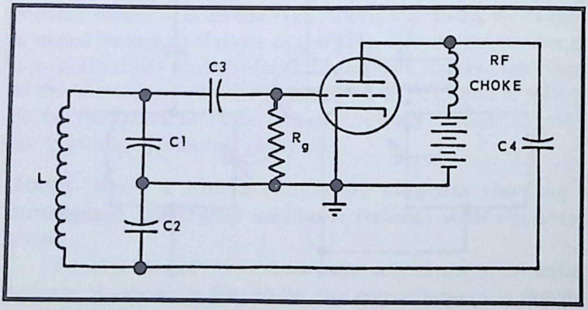


Fig. 10-26. Colpitts oscillator circuit.

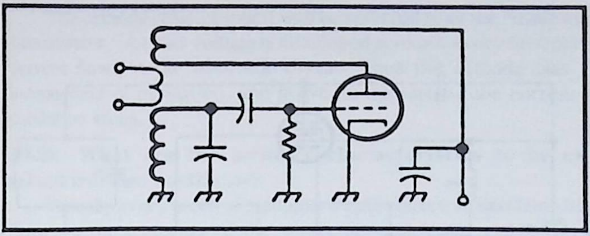


Fig. 10-27. Tuned-grid Armstrong triode oscillator circuit.

The series circuit differs from the shunt circuit in plate supply. Note in Fig. 10-27 that B+ is supplied to the plate through the tickler wiring. And note the bypass capacitor in the B+ line.

10-26 Draw a simple schematic diagram of an electron-coupled oscillator, indicating voltage polarities.

Actually a modified version of the Hartley, the electron-couple oscillator (Fig. 10-28) combines the functions of both an oscillat and an amplifier. The control grid's tank circuit, the control an screen grids, and the cathode form a series-fed oscillator with the screen grid serving as the plate. Capacitor C2 places the screen at zero potential (rf) and, like C3, bypasses the plate supply. The output tuned circuit is in the plate circuit, so the only coupling path is the electron stream between grid tank and plate tank (hence the circuit's name).

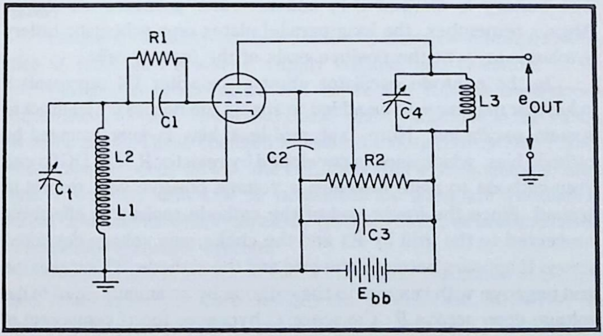


Fig. 10-28. Electron-coupled oscillator circuit.

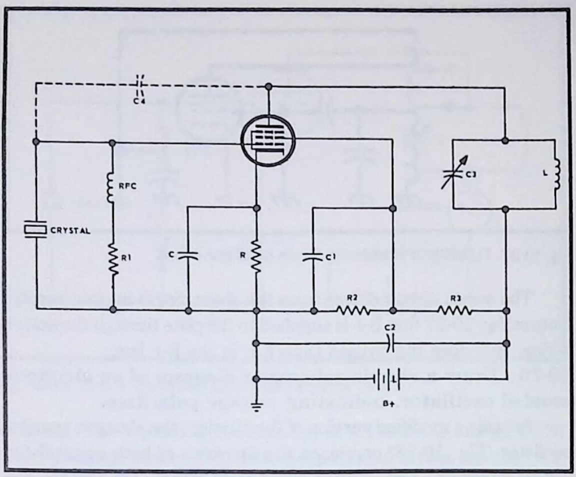


Fig. 10-29. Pentode crystal oscillator circuit.

10-27 Draw a simple schematic of a pentode crystal oscillator, indicating voltage polarities.

A pentode oscillator such as the one shown in Fig. 10-29 is a good deal more common than a triode crystal oscillator because it requires far less excitation to drive the tube to full power output. The battery is marked B+, and no other polarities are shown. Always remember, the long parallel plates on a schematic battery symbol represent the positive ends of the battery cells.

In the pentode oscillator shown, capacitor C4 represents a value that may have to be added to supply the necessary feedback to sustain oscillation. Note that grid-leak bias is supplemented by cathode bias, which itself is developed by resistor R. The DC flowing from cathode to plate develops a voltage positive with respect to ground. Since the lower end of the cathode resistor is effectively connected to the grid by R1 and the choke, any voltage developed across R appears between the grid and the cathode. This makes the grid negative with respect to the cathode by an amount equal to the voltage drop across R. Capacitor C bypasses the rf component of plate current around the cathode resistor.

The cathode resistor might well be referred to as the "minimum bias resistor," for bias voltage is developed across it every time plate current flows in the oscillator circuit. Thus the cathode bias is independent of oscillation, and prevents excessive tube current if oscillation stops.

10-28 What are the primary characteristics to be expected from an oscillator?

Virtually every piece of eqiupment that utilizes an oscillator has two main requirements of the oscillator—amplitude stability and frequency stability. The rigidity with which these requirements must be met depends on the accuracy demanded of the equipment.

Amplitude stability refers to the ability of the oscillator to maintain a constant amplitude output waveform. The less the deviation from a predetermined amplitude, the better is the amplitude stability.

Frequency stability refers to the ability of the oscillator to maintain the desired operating frequency. The less the oscillator drifts from the operating frequency, the better is the frequency stability.

10-29 What are the visible indications of a "soft" tube?

A "soft" tube is often characterized by a bluish haze between its elements when it is under full excitation. Also, plate current may fall off rapidly after excitation.

10-30 What factors affect frequency stability in an oscillator?

Frequency stability can be affected by changes in temperature, tank Q, reflected I^2R losses, supply voltage, and vibration.

Changes in temperature will cause the tube interelectrode capacitances to vary. It will also cause slight variations in the values of tank L and C. These changes will shift the output frequency. Since these changes occur slowly, the resultant shift in frequency is called drift. Frequency drift can be minimized by adequate ventilation, circuit components which can easily dissipate heat, or in some cases, a temperature control system.

Mechanical vibration can cause the same variations in component values as temperature changes did. In this case, however, the resultant frequency shift is more rapid in nature. The oscillator chassis is often shock mounted to overcome this problem.

Variations in supply voltage will change the operating point of the circuit and cause circuit instability. This can be overcome by use of a regulated power supply.

The load impedance, reflected into the tank circuit, has a great effect upon the frequency stability of the oscillator. The reflected impedance may contain both resistive and reactive components. The resistive component will lower the Q of the tank circuit, and the reactive component will alter the resonant frequency. When the Q of the tank is very high and the reflected impedance is small, the effect on the resonant frequency and tank Q is negligible. The lower the effective Q of the tank the greater will be the effect of a change in load impedance on the resonant frequency. High Q tanks and loose coupling reduce the frequency instability caused by these factors.

10-31 What are the characteristics of a capacitor input filter system as compared with a choke input filter system? What is the effect upon a filter choke of a large value of direct current?

Capacitor Input Filter. A capacitor input filter with no load produces a terminal voltage almost equal to the peak of the applied AC voltage. As the load increases, the terminal voltage drops because the current draw by the load prevents the capacitor from retaining its charge. This type of filter is undesirable for applications that require a large current, because the peak current that must flow in the diodes to charge the input capacitor may damage the diodes. Since the output voltage falls as the output current is increased, this type of filter has relatively poor regulation, as shown in Fig. 10-30. It may be used, however, where the load is light or very constant.

Choke Input Filter. The regulation of choke input filters may be better understood by considering a specific type of filter—the L-type. At no load, the output voltage of the choke input filter is nearly equal to the peak voltage of the applied AC, as with the capacitor input filter (see Fig. 10-30). This high voltage can be obtained because, with no load current being drawn, the capacitor can be charged to the peak voltage. However, if only a small load current is drawn, the output voltage falls sharply to some lower value. As the load current increases beyond the value indicated by point A in the illustration, there is very little change in voltage except that which takes place in the DC resistance of the choke coil. Since the voltage at the output of a choke input filter changes very little over a wide range of load, a choke input filter has good regulation.

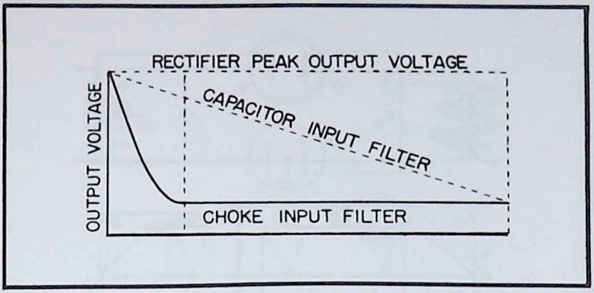


Fig. 10-30. Capacitor input filter performance.

The use of a choke input filter prevents load current from building up or dropping quickly. If the inductance is made large enough, the current becomes nearly constant. The inductance prevents the current from ever reaching the peak value that would be reached without the inductance, so the output voltage never reaches the peak value of the applied AC. A large value of current keeps the filter's output voltage down, but the voltage remains quite constant, even with current decreases and increases.

10-32 Name the principal types of power supply filter circuits.

The principal types of power supply filter circuits are (1) capacitance filter, (2) inductance filter, (3) L-type filter, and (4) pi type filter.

The action of a capacitance filter is illustrated in Fig. 10-31, where a half-wave rectifier with its output applied to a capacitor is shown. The peak AC input is 100 volts. As the first positive half cycle is applied to the plate of V_1, the tube conducts and capacitor C_1 begins to charge. The rate of charging C1 is limited only by the reactance of the transformer secondary winding and the plate resistance of the rectifier. Therefore, the capacitor voltage rises nearly as fast as the input pulse. When the input voltage starts to decrease, the voltage of the capacitor does not follow. Instead, the voltage remains constant since the capacitor does not have a discharge path.

Assume that C_1 charges to 80 volts during the first half of the input cycle. Since C_1 has no discharge path, the cathode of V_1 will remain at a positive 80 volt potential. The plate-to-ground voltage

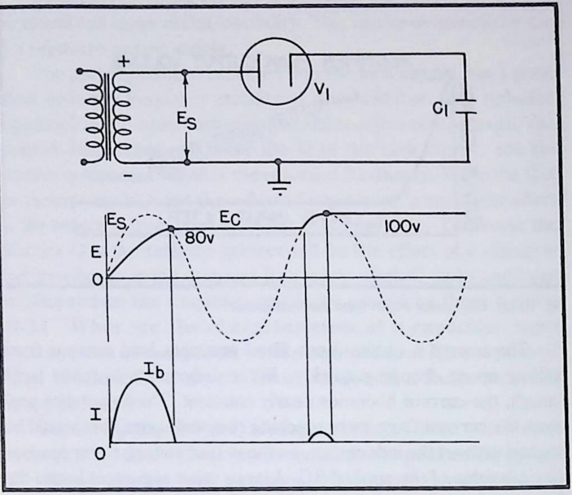


Fig. 10-31. Capacitance filter circuit and performance curves.

must therefore exceed +80 volts before V_1 will again conduct. During the positive half of the second input cycle when the plate-to-ground voltage reaches a value greater than a +80 volts, V_1 goes into conduction and allows further charging of C_1. Assuming that the capacitor C_1 now charges to 100 volts, V_1 can no longer conduct since the plate can no longer become positive with respect to the cathode. The output across the capacitor is now pure DC equal to the peak value of the input.

A similar analysis can be made of the action of a capacitor filter upon a full wave rectifier. Operation is the same with the exception that E_C will reach a value that approximates the peak value of E input much faster. This is illustrated in Fig. 10-32.

An *inductor* may also be used as a filter component because of its ability to store energy in the form of a magnetic field. Because an inductor resists changes in the magnitude of current flow, it will be placed in series with the rectifier and the load rather than in parallel. Since the inductor used in rectifier filter circuits "chokes" or stops the passage of ripple into the load it is called a filter choke.

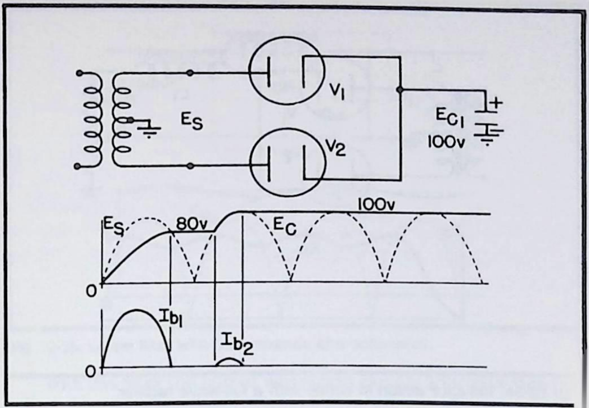


Fig. 10-32. Capacitor filter action upon a full wave rectifier.

Consider the action of a large inductor in series with the output of a half-wave rectifier. Any change in the current through the coil, either an increase or decrease, is opposed by the inductor thus affecting the voltage output as shown in Fig. 10-33. The ripple has been reduced but the output is not good enough for most practical applications.

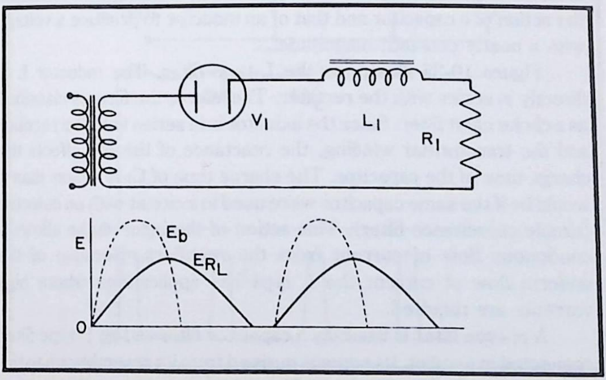


Fig. 10-33. Inductor action in series with a half-wave rectifier.

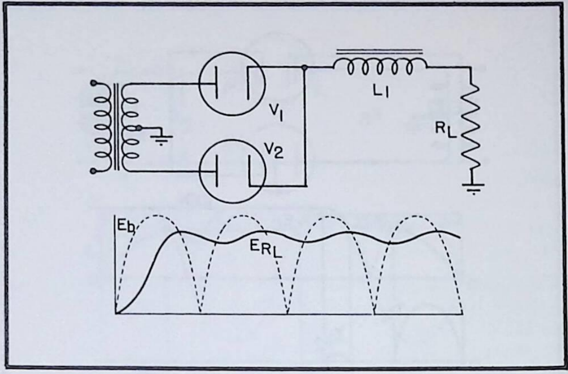


Fig. 10-34. Inductor action in series with a full-wave rectifier.

If the same high inductance coil is placed in series with the output of a full wave rectifier a more useful output is obtained as indicated in Fig. 10-34.

The ripple voltage present in a rectifier output cannot be adequately reduced in many cases by either the simple capacitance or inductance filter. Much more effective filtration results if both capacitors and inductors are used. The *L-type* filter, so named because of its resemblance to an inverted L, is a filter that combines the action of a capacitor and that of an inductor to produce a voltage with a nearly constant magnitude.

Figure 10-35 illustrates the L-type filter. The inductor L is directly in series with the rectifier. Therefore, the filter is classified as a choke input filter. Since the inductor is in series with the rectifier and the transformer winding, the reactance of the coil affects the charge time of the capacitor. The charge time of C_1 is longer than it would be if the same capacitor were used in a circuit with no inductor (simple capacitance filter). This action of the input choke allows a continuous flow of current from the rectifiers. Because of the uniform flow of current the L type has applications where high currents are required.

A pi-type filter is basically a capacitor filter and an L-type filter connected in parallel. Its name is derived from its resemblance to the Greek letter Pi. The circuit of Fig. 10-36 is a pi-type filter.

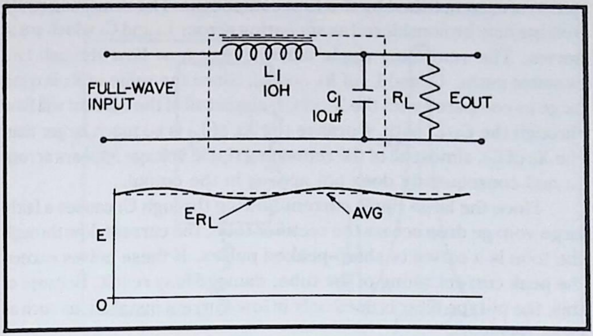


Fig. 10-35. L-type filter with performance characteristics.

With this filter the output waveform closely approximates pure DC.

The first (input) capacitor C_1 represents a low-impedance patl through which most of the ripple current flows. Since the X_C of C_1 is low, very little ripple voltage appears across C_1. Most of the filtering

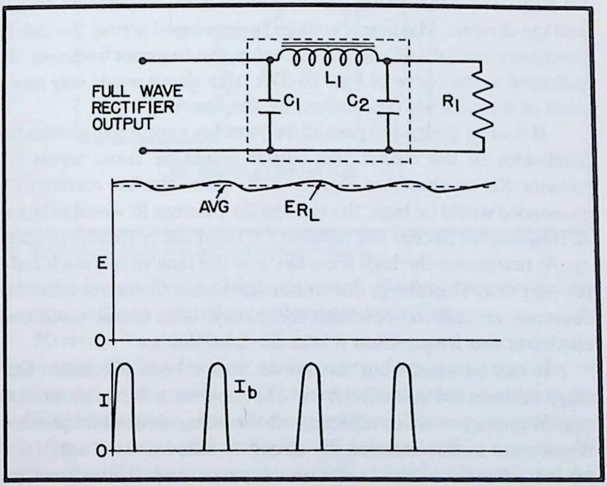


Fig. 10-36. Pi-type filter with performance characteristics.

action is accomplished by this first component. The remaining ripple voltage may be considered as appearing across L_1 and C_2 which are in series. The remaining ripple current may now flow through two possible paths, C_2 and L_1 of R_L and L_1. Since the value of R_L is quite large as compared with the X_C of C_2, almost all of the current will flow through the C_2-L_1 path. Because the X_L of L_1 is so much larger than the X_C of C_2, almost all of the remaining ripple voltage appears across L_1 and consequently does not appear in the output.

Since the large ripple current flowing through C_1 causes a fairly large voltage drop across the rectifier tube, the current flow through the tube is a series of sharp-peaked pulses. If these pulses exceed the peak current rating of the tube, damage may result. Because of this, the pi-type filter is used only in low-current installations such as radio receivers.

10-33 Discuss bandpass and band-elimination filter operation.

A parallel resonant circuit may be used as either a bandpass filter or a band-elimination filter depending on where the output terminals are placed. If it is desired to pass only a certain band of frequencies, the output is taken across the tank circuit as in Fig. 10-37A. The tank circuit impedance and the resistor R_2 form a voltage divider. Maximum voltage is developed across the tank at resonance and falls off, above and below the resonant frequency. As indicated in the curve of Fig. 10-37A, this circuit would only pass a band of frequencies determined by the bandwidth.

If it were desired to pass all frequencies except those within the bandwidth of the circuit the output would be taken across the resistor R_2, as shown in Fig. 10-37B. Since the line current OFF resonance would be high, the voltage drop across R_2 would be high at all frequencies except the bandwith around the resonance frequency. At resonance the high impedance of the tank circuit would make I_{line} very low. Therefore, the output waveform shows a considerable decrease around the resonant frequency. This circuit would then eliminiate the frequencies within the bandwidth.

It can be seen from the above, that a bend elimination filter might be inserted in the front end of a receiver to "trap" an interferring frequency without affecting all the other desired frequencies. When used in this manner the circuit is called a wave trap.

10-34 Discuss the relative merits and limitations (as used in power supplies) of the following types of rectifiers:

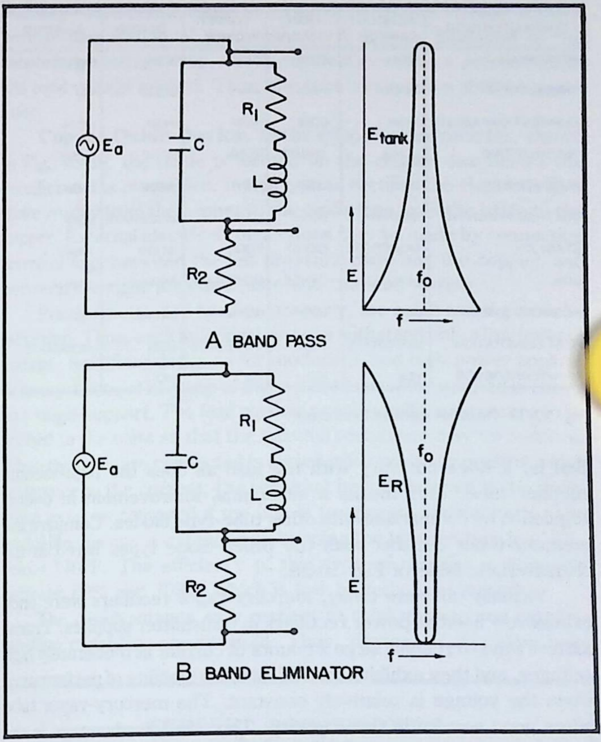


Fig. 10-37. Band pass and band eliminator filters.

mercury vapor diode, high-vacuum diode, copper-oxide-rectifier, silicon rectifier, selenium rectifier.

Mercury-Vapor Diode. Mercury-vapor tubes are inherently high-current devices because of the current-carrying capability of the ionized gas in the envelope. The ions make it unnecessary to rely on filament heat alone as an electron source. The very low voltage drop across the tube makes it highly efficient in rectifier service—in practice, the efficiency can approach 90%. Another advantage of the mercury-vapor tube is the fact that the voltage drop is constant—

CHARACTERISTIC	MERCURY VAPOR	HIGH VACUUM	COPPER OXIDE	SILICON	SELENIUM
EFFICIENCY	HIGH	LOW	FAIR	HIGH	FAIR TO GOOD
REGULATION	GOOD	POOR	—	GOOD	—
CURRENT CAPABILITY	HIGH	LOW	HIGH	HIGH	HIGH
WARMUP TIME	LONG	SHORT	NONE	NONE	NONE
RUGGEDNESS	LOW	LOW	HIGH	HIGH	HIGH
VOLTAGE HANDLING	MODERATE	HIGH	LOW	MODERATE	LOW
STABILITY	MODERATE	GOOD	POOR	GOOD	FAIR
SIZE	LARGE	LARGE	MODERATE	SMALL	LARGE
FILAMENT CURRENT	LOW	HIGH	NONE	NONE	NONE
HEAT GENERATION	MODERATE	HIGH	MODERATE	LOW	MODERATE
RF INTERFERENCE	YES	NO	NO	NO	NO

Fig. 10-38. Rectifier comparison chart.

that is, it does not vary with the load as does the high-vacuum rectifier tube. This means a substantial improvement in overall regulation by comparison with other tube-type diodes. Compare the mercury-vapor rectifier with the other diode types listed in the characteristic table of Fig. 10-38.

Virtually obsolete today, mercury-vapor rectifiers were once extensively used as power rectifiers in transmitter supplies. Transmitters tend to require large amounts of current at moderately high voltages, and they exhibit a great deal more stability of performance when the voltage is relatively constant. The mercury-vapor tube offers good service in this capacity. The chief disadvantage is the warmup requirement. The filament must be allowed to heat the mercury pool until it vaporizes—before high voltage is applied to the tube.

High-Vacuum Diode. Until quite recently, this tube has been the workhorse of the diodes for electronics applications. High-vacuum rectifiers have traditionally been used in power supplies for receivers, transmitters, and audio equipment—and also as limiters, detectors, and clippers for radio systems.

As a power rectifier, the high-vacuum tube offers a high peak-inverse-voltage capability, and has enjoyed a reputation for with-

standing considerable abuse in terms of excessive voltage without serious degradation of performance. A serious limitation is the tube's large voltage drop, which manifests itself as a percentage of the total voltage applied. Thus, the tube's regulation ability is quite poor.

Copper-Oxide Device. In the copper-oxide recitifer, shown in Fig. 10-39, the oxide is formed on the copper disc before the rectifier unit is assembled. In this type of rectifier the electrons flow more readily from the copper to the oxide than from the oxide to the copper. External electrical connections may be made by connecting terminal lugs between the left pressure plate and the copper, and between the right pressure plate and the lead washer.

For the rectifier to function properly, the oxide coating must be quite thin. Thus, each individual unit can withstand only a low inverse voltage. Rectifiers designed for moderate- and high-power applications must consist of many of these indivdual units mounted in serie on a single support. The lead washer enables uniform pressure to b applied to the units so that the internal resistance may be reduced. When the units are connected in series, they normally present a high resistance to the current; the resultant heat developed in the resistance must be removed if the unit is to operate satisfactorily. The useful life of a unit is extended by keeping the temperature low, i.e., below 140°F. The efficiency of this type of rectifier is generally between 60% and 70%—which is low by today's standards.

The disadvantages with respect to total voltage and current-handling capability are manifold. Thus, devices of this type have

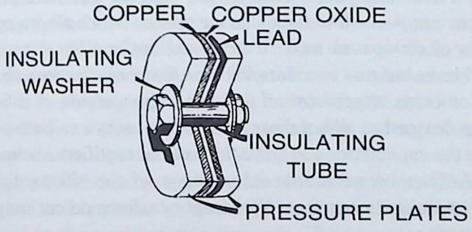


Fig. 10-39. A copper-oxide rectifier.

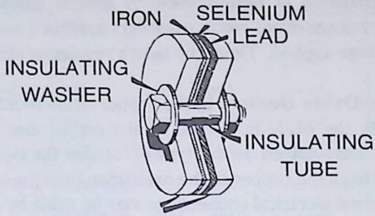


Fig. 10-40. A selenium rectifier.

traditionally had restricted usefulness. A typical application of the copper-oxide device has been as a rectifier in measuring instruments. Today the silicon rectifier is used almost exclusively.

Selenium Device. Selenium rectifiers function in much the same manner as copper-oxide rectifiers. A selenium rectifier is shown in Fig. 10-40. Such a rectifier is made up of an iron disc that is coated with a thin layer of selenium. In this type of rectifier the electrons flow more easily from the selenium to the iron than from the iron to the selenium. This device may be operated at a somewhat higher temperature than a copper-oxide rectifier of similar rating. The efficiency is between 65% and 85%, depending on the circuit and loading.

Selenium rectifiers develop considerable heat when used in high-current applications and are thus usually constructed in the form of a heat dissipator; that is, the rectifier units are placed in series but are separated by a thin air space, which allows optimum radiation of dissipated heat. Traditional applications for selenium "stacks" have been as rectifiers for tube filaments, battery chargers, and automotive alternators. Like the copper-oxide rectifier, the selenium device has all but disappeared from service. To learn why, examine the capabilities and limitations of the rectifiers shown in Fig. 10-38. As can be seen, the advantages of the silicon diode are virtually overwhelming in every category where power output is a requirement.

10-35 List the most important diode electron tube ratings and explain the meaning of each.

Each diode has certain voltage, current and power values which should not be exceeded in normal operation. These values are called ratings. The following are the most important diode electron tube ratings:

Plate dissipation is the maximum average power, in the form of heat, which the plate may safely dissipate.

Maximum average current is the biggest average plate current which may be handled continuously. It is based on the tube's permissible plate dissipation.

Maximum peak plate current is the highest instantaneous plate current that a tube can safely carry, recurrently, in the direction of normal current flow.

Peak inverse voltage (PIV) is the highest instantaneous plate voltage which the tube can withstand recurrently, acting in a direction opposite to that in which the tube is designed to pass current (i.e., plate negative—cathode positive).

It should also be noted that the correct filament or heater voltage and current is required for proper operation of an electron tube. If heater current is too low, the cathode will not emit sufficient electrons. This will result in low emission, and the tube will be incapable of proper operation. Excessive heater or filament current may reduce the life of the tube or destroy the heater or filament.

10-36 What is the object of a voltage regulator?

Most electronic equipment performs satisfactorily with some variations in supply voltage. However, operation of many circuits is sensitive to minimal changes in supply voltage. Thus, use of a voltage regulator is required.

An electronic voltage regulator is connected between the power supply and load impedance to maintain the output voltage at a specific value. The regulator circuit reacts automatically within its design limits to compensate for deviations in output voltage due to changes in line voltage or variations in load impedance.

10-37 Draw a simple solid state shunt voltage regulator and explain its operation.

Figure 10-41 depicts a solid state shunt regulator. Q1, in parallel with the load impedance, is an NPN transistor with the collector connected to the positive side through CR1, a zener diode. CR1, when reverse biased to its breakdown voltage by R2, maintains a constant reference voltage at the emitter of Q1. The base voltage of

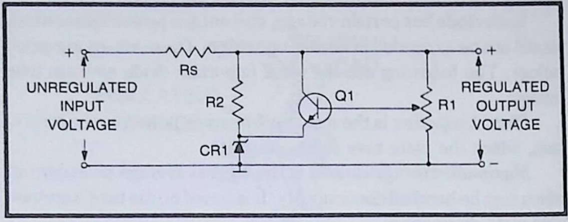


Fig. 10-41. Solid state shunt voltage regulator circuit.

Q1 is determined by the setting of potentiometer R1. This voltage is adjusted so that the base is positive with respect to the fixed emitter potential, forward biasing Q1, and causing it to conduct. The setting of R1 determines the amount of current through Q1.

The regulated output voltage is equal to the available supply voltage minus the drop across R_s, the series dropping resistor. The voltage drop across Rs is controlled by the amounts of current drawn by Q1. Thus, the setting of R1 will determine the value of the regulated output voltage.

Regulation is accomplished in the following manner. If, for any reason the output voltage increases, the drop across R1 will increase. This will cause an increased positive potential at the base of Q1. Since Q1's emitter is at a fixed potential, due to CR1, the more positive base will cause Q1 to conduct more. Current flow through R_s will increase due to the increased transistor current. This will cause an increased voltage drop across R_s, reducing the output voltage to the desired level.

For a decrease in output voltage, the regulation process is reversed. The decreased drop across R1 will decrease the forward bias of Q1, causing the transistor to conduct less. Current through R_s will decrease, causing voltage across R_s to decrease, increasing the output voltage.

10-38 How are solid-state diodes rated? How may two or more diodes be connected to increase their peak inverse voltage (PIV) ratings?

Solid-state diodes may be rated for peak inverse voltage (PIV) rms supply or input voltage, average forward current, peak one-cycle surge current, peak forward current, forward voltage drop, and thermal resistance. Of all these, the most important are those

which correspond to the tube ratings: PIV, average forward current, and peak one-cycle surge current.

PIV is the maximum voltage which can be applied "in reverse" to the diode before it breaks down and permits current flow "against the stream"; when exceeded, instant destruction of the diode usually results. If the diode is connected to a capacitor, diode PIV should be at least twice the peak value of applied AC voltage; otherwise, PIV should be at least equal the peak of the applied AC.

Two or more diodes can be connected in series to increase their PIV ratings, provided that equalizing resistors are connected in parallel with each as shown in Fig. 10-42. These resistors assure that each diode gets only its share of the applied voltage; otherwise, most of the voltage would appear across the diode with highest back resistance.

Average forward current is the maximum current which the diode can pass without overheating, on a steady basis.

Peak one-cycle surge current, usually at least 10 times greater than average current, is the maximum current which can be tolerated on a "one-time" basis without destruction of the unit. Surges occur each time the power supply is turned on, as the filter capacitors charge, and if this rating is ignored with semiconductors, diodes will behave like expensive (and rapid) fuses every time.

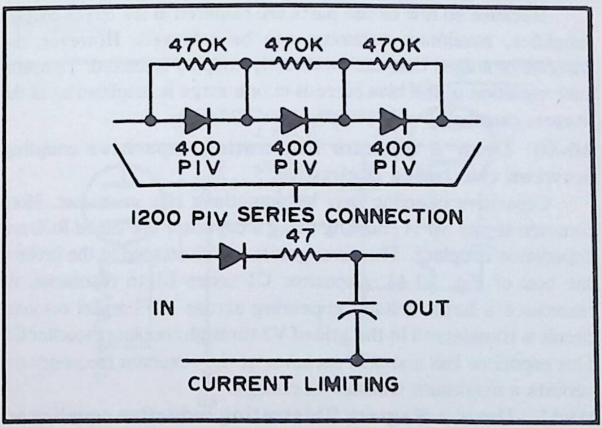


Fig. 10-42. Diodes in series increase their PIV ratings.

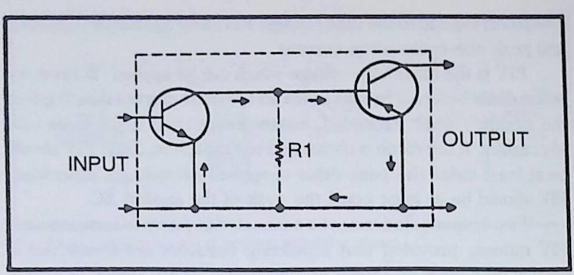


Fig. 10-43. Direct-coupled amplifier circuit.

10-39 Draw a simple schematic diagram of a pnp transistor directly coupled to an npn transistor. Explain its operation.

The direct-coupled amplifier shown in Fig. 10-43 is used for amplification of DC signals and very low frequencies. In the circuit shown, an npn transistor is connected directly to a pnp transistor. The direction of current is shown by the arrows. If the collector current of the first stage is larger than the base current of the second stage, then a collector load resistor (R1) must be connected as indicated.

Because so few circuit parts are required in the direct-coupled amplifier, maximum economy can be achieved. However, the number of stages that can be directly coupled is limited. Temperature variation of the bias current in one stage is amplified by all the stages, causing severe temperature instability.

10-40 Draw a diagram illustrating capacitive coupling between two tuned rf circuits.

Capacitive coupling may be something of a misnomer. More common terms for rf coupling using a capacitor are tuned RCL and impedance coupling. The arrangement is illustrated in the broken-line box of Fig. 10-44. Capacitor C1 tunes L1 to resonance. At resonance a large voltage appearing across the parallel resonant circuit is transferred to the grid of V2 through coupling capacitor Cc. This capacitor has a small reactance at the resonant frequency and permits a maximum transfer of energy.

10-41 Draw a diagram illustrating inductive coupling between two tuned rf circuits.

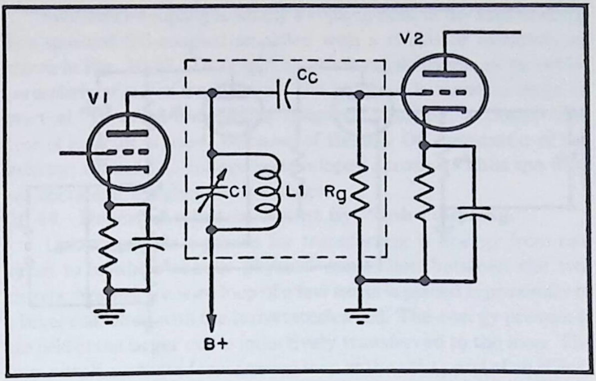


Fig. 10-44. Capacitive coupling in a tuned RF circuit.

Inductive coupling, also referred to as transformer coupling, is pictured in Fig. 10-45. The method shown is called double-tuned inductive coupling, because both inductances in the coupling network may be tuned with the parallel capacitances. In practice, only one of the two inductances need have a variable capacitor across it. In such a case the arrangement would be called single tuned inductive coupling.

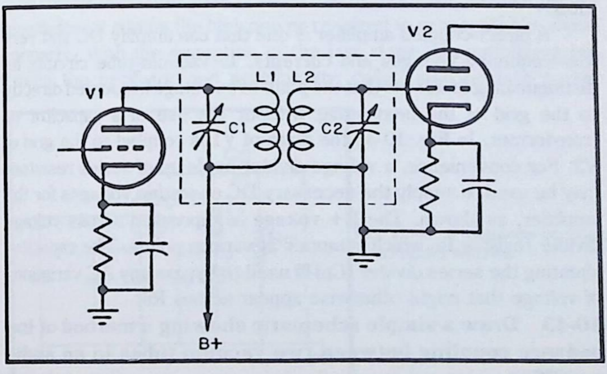


Fig. 10-45. Inductive coupling in a tuned RF circuit.

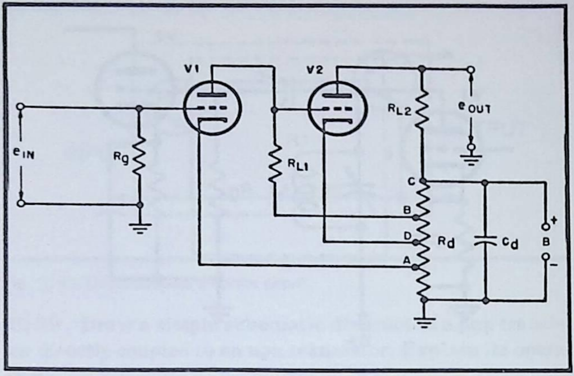


Fig. 10-46. Direct coupling in an af amplifier.

In the circuit shown coil L1 is the primary and coil L2 the secondary. Capacitor C1 tunes L1 to resonance at the signal frequency. A large signal voltage is produced across the high impedance of the parallel resonant circuit formed by L1 and C1. The large circulating tank current in the primary creates a magnetic field which induces a voltage in the secondary (L2).

10-42 Draw a diagram illustrating direct, or Loftin-White coupling between two stages of audio-frequency amplification.

A direct-coupled amplifier is one that can amplify DC and very low-frequency voltages and currents. In vacuum-tube circuits its distinguishing feature is that the plate of one stage is coupled directly to the grid of the next stage without the use of a capacitor or transformer. In Fig. 10-46 the plate of V1 is coupled to the grid of V2. For convenience, a voltage divider made up of series resistors may be used to supply the necessary DC operating voltages for the amplifier, as shown. The B+ voltage is impressed across voltage divider resistor R_D which is tapped at various points. The capacitor shunting the series divider (C_D) is used to bypass any AC variations of voltage that might otherwise appear across R_D.

10-43 Draw a simple schematic showing a method of impedance coupling between two vacuum tubes in an audio amplifier.

Impedance coupling is simply a replacement of the load resistor in a standard RC-coupled amplifier with a choke or inductor, as shown in Fig. 10-47. To obtain as much amplification as possible, particularly at lower frequencies, the inductor is made as large as practical. To avoid undesirable magnetic coupling, a closed-shell type of inductor is used. Because of the low DC resistance of the inductor, a small DC voltage is developed across it. Thus the tube will operate at a higher plate voltage.

10-44 Describe what is meant by "link coupling."

Link coupling is a means for transferring rf energy from one circuit to another without physical connection between the two circuits. Normally, a wire loop of a few turns is placed in proximity to a larger coil, often with the turns interleaved. The energy present in the field of the larger coil is inductively transferred to the loop. The loop is itself connected to a second loop at the other end of an rf line, and the second loop is coupled to a coil in the succeeding stage or circuit.

10-45 Draw a block diagram of an AM transmitter.

An AM transmitter can be divided into two major sections, according to the frequencies at which the sections operate. One section is called the rf unit and is the section of the transmitter used to generate the rf carrier wave. As illustrated in the block diagram of Fig. 10-48, the carrier originates in the oscillator stage, where it is generated as a constant-amplitude, constant-frequency sine wave. The carrier must then pass through one or more stages of amplification before it attains the high power required to propagate the signal properly. With the exception of the last stage, the amplifiers between the oscillator and antenna are called intermediate power

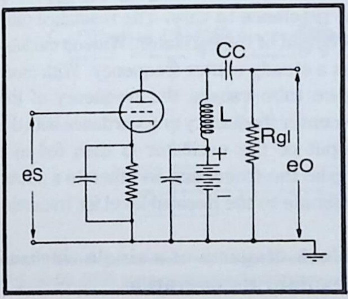


Fig. 10-47. Impedance coupling in an audio amplifier.

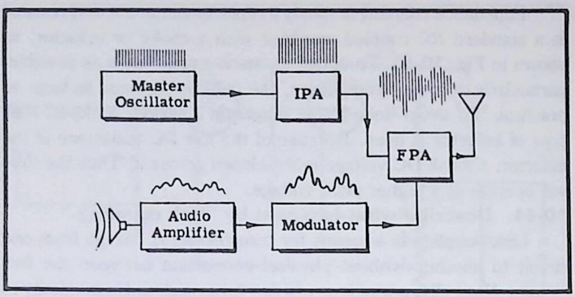


Fig. 10-48. AM transmitter block diagram.

amplifiers (IPA). The last stage, which connects to the antenna, is called the final power amplifier (FPA), or just the final.

The second section of the transmitter contains the audio circuitry. This section takes the minute signal from the microphone and increases its amplitude an amount necessary to fully modulate the carrier. The last audio stage applies its signal to the carrier and is called the modulator.

10-46 Draw a simple block diagram of an FM transmitter and briefly explain its operation.

In frequency modulation (FM), the modulating signal combines with the carrier in such a way as to cause the frequency of the resultant wave to vary in accordance with instantaneous amplitude of the modulating signal.

Figure 10-49 is the block diagram of a narrow band frequency modulation (NBFM) transmitter. The modulating signal is applied to a reactance tube causing the reactance to vary. The reactance tube is connected across the tank circuit of the oscillator. With no modulation, the oscillator generates a steady center frequency. With modulation applied, the reactance tube causes the frequency of the oscillator to vary around the center frequency in accordance with the modulating signal. The output of the oscillator is then fed to a frequency multiplier to increase the frequency and then to a power amplifier to increase the amplitude to the desired level for transmission.

10-47 Draw a simple block diagram of a single sideband transmitter and briefly explain its operation.

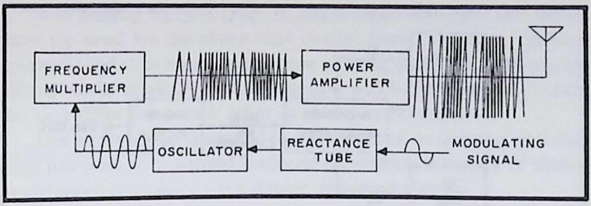


Fig. 10-49. NBFM transmitter block diagram.

A single sideband (SSB) transmitter translates audio frequency intelligence to desired radio frequencies. Unlike the amplitude modulated (AM) transmitter, usually, only one of the sidebands, either the upper or the lower sideband, is transmitted while the remaining sideband and the carrier are suppressed.

Figure 10-50 is the block diagram of an SSB transmitter. The audio amplifier increases the amplitude of the signal to a level adequate to operate the SSB generator. Usually the audio amplifier is just a voltage amplifier.

The SSB generator combines the audio input and the carrier input from the frequency generator to produce the two sidebands, and then suppresses the carrier. The two sidebands are then fed to a filter which selects the desired sideband and suppresses the other one.

The SSB generator in most cases operates at a very low frequency compared with the normal transmitted frequency. It is

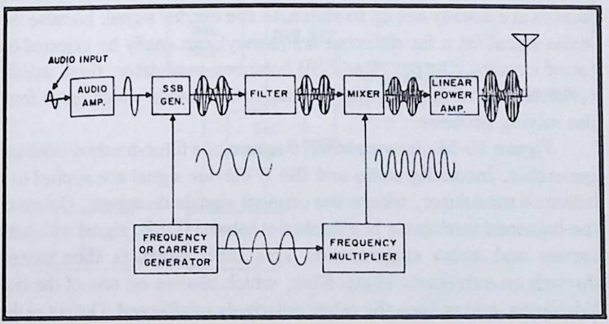


Fig. 10-50. SSB transmitter block diagram.

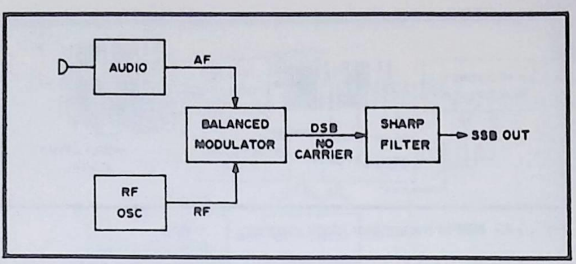


Fig. 10-51. Filter-method sideband generator block diagram.

necessary, therefore, to convert (or translate) the sideband output from the filter to the desired frequency. This is the prupose of the mixer stage. To obtain a higher carrier frequency for the mixer stage, a second output is obtained from the frequency generator and fed to a linear power amplifier to build up the level of the signal for transmission.

10-48 Name and discuss the two most popular methods of sideband generation in an SSB transmitter. Draw a simple block diagram of each system.

At least three different techniques for sideband generation are known, but only two of these are used in practice. They are known as the "filter method" and the "phasing method."

Both the filter and phasing methods make use of "balanced modulator" circuits, which are special types of mixers which eliminate one of the two input signals from their outputs. These balanced mixers are usually set up to eliminate the carrier signal, because the audio signal (at a far different frequency) can easily be rejected by tuned circuits. Output of an SSB balanced modulator, then, usually consists only of the two mirror-imaged sidebands which result from the mixing process.

Figure 10-51 shows a block diagram of a filter-method sideband generator. Incoming audio and the rf carrier signal are applied to a balanced modulator, where the original signals disappear. Output of the balanced modulator is a double-sideband (DSB) signal with both carrier and audio suppressed. This DSB signal is then passed through an extremely sharp filter, which shaves off one of the two sidebands, and passes the other relatively unaffected. Output of the filter, therefore, is the desired single sideband signal.

The phasing method (Fig. 10-52) is more complex, but eliminates the need for the sharp (and costly) filter. Incoming signals, both audio and rf, are applied to phase-shifting networks. The phase shift networks produce pairs of outputs, which are identical except that they differ from each other in phase by 90 degrees.

One audio-rf pair is applied to one balanced modulator, and the other pair goes to a second balanced modulator. Outputs of these two balanced modulators are double sideband signals.

The balanced-modulator outputs differ from each other in phase, however. Because of the phase shift introduced into the signals before mixing, one sideband (either the upper or the lower one) will have the same phase in both modulator outputs, while the other sideband will have a 180-degree phase difference between on modulator output and the other.

The two outputs are combined in a summing network, wher the sideband with no phase difference survives while the one with 180-degree phase difference cancels itself out. The output of the summing network is, therefore, the desired single sideband signal.

Both the filter method and the phasing method have advantages and disadvantages. The filter is simpler in concept, but requires

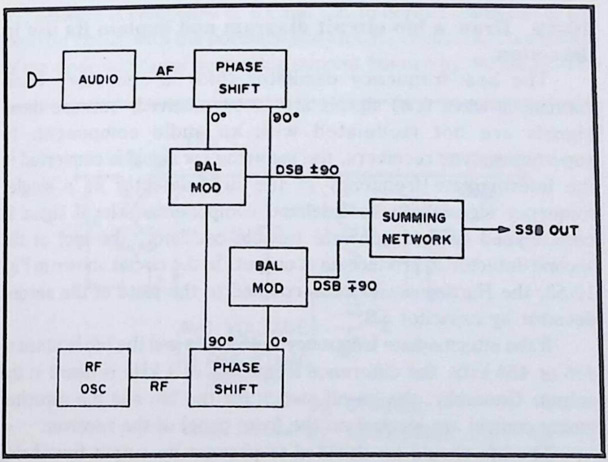


Fig. 10-52. Phasing-method sideband generator block diagram.

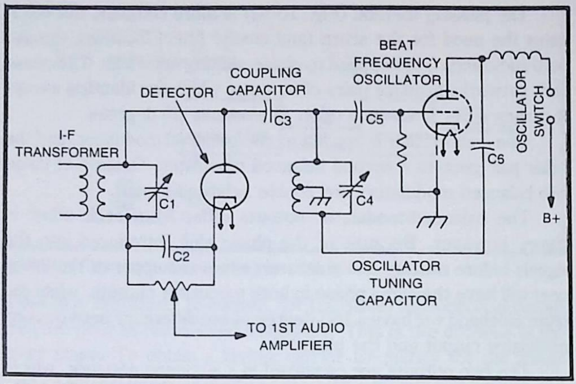


Fig. 10-53. Bfo circuit diagram.

components which are usually more costly. On the other hand, phasing is less expensive but requires more critical adjustments. Either technique is capable of producing outstanding results—or garbage, depending upon the skill and care of the operatior.

10-49 Draw a bfo circuit diagram and explain its use in detection.

The beat-frequency oscillator (bfo) is necessary when continuous-wave (cw) signals are to be received, because these signals are not modulated with an audio component. In superheterodyne receivers, the incoming cw signal is converted to the intermediate frequency at the first detector as a single-frequency signal with no sideband components. The if signal is heterodyned (with a separate tunable oscillator, the bfo) at the second detector to produce an af output. In the circuit shown in Fig. 10-53, the Hartley oscillator is coupled to the plate of the second detector by capacitor C3.

If the intermediate frequency is 455 kHz and the bfo is tuned to 456 or 454 kHz, the difference frequency of 1 kHz is heard in the output. Generally, the on-off switch for the bfo and the capacitor tuning control are located on the front panel of the receiver.

The bfo should be shielded to prevent its output from being radiated and combined with desired signals ahead of the second

detector. If avc voltage is to be used, it should be obtained from a separate diode isolated from the second detector. One way is to couple the output of an if amplifier (ahead of the second detector) to the avc diode; otherwise the output of the bfo would be rectified by the second detector and would develop an avc voltage even during conditions of no input signal.

10-50 How is automatic volume control achieved in a radio receiver?

Automatic volume control, or avc, amounts to applying degenerative feedback in a controlled manner to maintain a relatively constant output amplitude of received signals. A diode detector's output consists of a DC voltage that varies at an audio rate representing the rate of the incoming modulation. The stronger the signal at the antenna of the receiver, the higher this DC voltage. An avc circuit is a circuit that accepts this signal (after filtering) and changes it to a level suitable for application to preceding stages so as to cause attenuation in these earlier stages.

The schematic diagram of a simple avc circuit used in conjunction with a series diode detector is shown in Fig. 10-54. Components T1, CR1, C1, and R1 constitute a normal series diode detector. The avc network is composed of R1 and C2. In normal operation of the detector circuit with the potential shown CR1 conducts. Conduction of the diode will cause a charging current (shown by dotted line) to

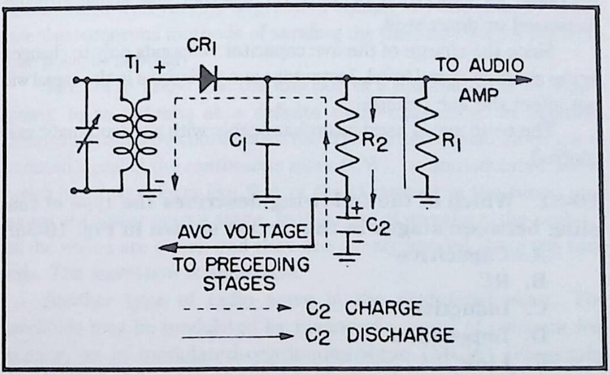


Fig. 10-54. Simple avc circuit schematic diagram.

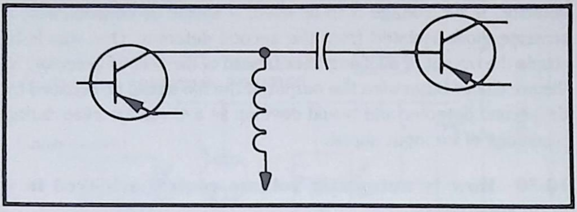


Fig. 10-55. Graphic for Question 10-51.

flow through the avc capacitor (C2) and avc resistor (R2). This charging current will cause C2 to assume the polarity shown. Resistor R2 and capacitor C2 form a voltage divider causing the voltage across C2 to be only a portion of the voltage present across output resistor R1.

When the potential across T1 reverse-biases the diode and charging current ceases to flow, C2 will begin to discharge. However, the discharge time constant of C2, R2, and R1 is chosen to be longer than the lowest audio frequency present in the output of the detector. Consequently, C2 will not discharge appreciably between peaks of the modulating signal, and the voltage across C2 will be a DC voltage. The voltage across C2 is proportional to the average carrier signal. Thus, if the signal strength should vary, the average of the carrier signal will vary. This will cause C2 to either increase or decrease its charge, depending on whether the signal strength increased or decreased.

Since the charge of the avc capacitor responds only to changes in the average signal level, instantaneous variations in the signal will not affect the avc voltage.

The term avc is used interchangeably with agc (automatic gain control).

10-51 Which of the following describes the type of coupling between stages in the circuit shown in Fig. 10-55?

A. Capacitive
B. RC
C. Inductive
D. Impedance
E. Link

Answer: *D*

Chapter 11

Emission Characteristics

The waves of rf energy leaving a transmitting system are its emissions. If everything is operating properly, the emissions can convey an intelligence that can be recovered at the receiver. Obviously, unwanted emissions can be a source of irritation.

The transmitter itself is a device for converting intelligence, such as voice or code, into electrical impulses for transmission through space from a radiating antenna. There are many forms of transmitters with varying degrees of complexity and power. There are also numerous methods of sending the desired information from one point to another.

Most of us know that the function of a transmitter is to supply power to an antenna at a definite radio frequency. In addition, information must be contained in the transmitted signal. One type of radiated signal is the *continuous wave* (CW), or unmodulated wave, which has a waveform like that of the rf current in the tuned tank circuit of a power output stage. In this type of waveform the peaks of all the waves are equal, and they are evenly spaced along the time axis. The waveform is sinusoidal.

Another type of radio wave is the *modulated wave*. The amplitude may be modulated by means of a signal of constant frequency, as in modulated-continuous-wave (MCW) telegraphy (rarely used). Likewise, the amplitude may be modulated by means

of speech, and in this case it is called *amplitude modulation* (AM). If the frequency of the wave is varied with time it is called *frequency modulation* (FM). If the AM carrier is suppressed, the signal may be referred to as *double sideband* transmission, and if the carrier and either the upper or the lower sidebands are suppressed, the signal is called *single-sideband* transmission. There are other types of modulation, such as pulse-time modulation, but these are not universally used in amateur radio.

A given transmitter operated on CW has a greater range than the same transmitter (for the same power output) operated on voice modulation. This condition results from the fact that all the intelligence is contained in the sidebands, and the fewer the number of sideband frequencies the greater will be the signal strength in the remaining sideband frequencies. In CW operation the sidebands do not extend very far on each side of the carrier, and all of the energy is therefore contained in a narrow band and not "wasted" in nonessential bands.

When voice modulation is used, the necessary sidebands are increased over those needed for CW. Each sideband requires a certain amount of energy, and therefore, in order to keep the energy level of all the essential sidebands up to the required level at the receiver, the transmitter must deliver more energy than is necessary with CW.

In an AM signal, the intelligence is carried in both sidebands. The amplitude of the intelligence is represented by the relative amplitude of either sideband, and the frequency of the intelligence is represented by the frequency difference between the carrier and either sideband. Since the intelligence contained in one sideband is a duplicate of the intelligence contained in the other sideband, only one sideband is required for communication. The other sideband may be eliminated by the use of filtering. As the carrier is totally unnecessary for the transmission of intelligence, it too may be filtered out. Such communication depends, however, upon the reinsertion of the carrier at the receiver in order to acquire the proper demodulated frequencies. This system is referred to as single-sideband suppressed carrier communication.

In this chapter we will cover substantially all of the areas pertaining to emission of signals that you are likely to encounter on the FCC exam. The last question in the chapter is one prepared by the FCC.

11-1 Define intermodulation distortion.

Intermodulation distortion (sometimes shortened to intermodulation, or simply intermod) is the unwanted modulation of the components of a complex wave by each other, producing waves having frequencies equal to the sums and differences of integral multiples of the component frequencies of the complex wave.

When two frequencies, f1 and f2, are detected by some nonlinear element, the result is intermodulation—or generation of a signal that is a combination of f1 or any of its harmonics with f2 or any of its harmonics (i.e., $f1 \pm f2$, $f1 \pm 2f2$, $2f1 \pm f2$, $f1 \pm 3f2$. etc.). Transmitter intermodulation typically occurs when the nonlinear element is the grid circuit of the final amplifier of one of the transmitters involved.

The source of an intermod problem may be difficult to spo because there are no easy methods by which an operator determine whether the intermod is a transmitter or a rece problem, and there is no direct method for determining which of transmitters is radiating the interfering signal other than to exam the areas where the intermod is occurring. If the signal occurs in bu one or two receivers and not in others tuned to the same frequency in the same area, the problem is probably due to a mixing action in the receiver itself.

When the frequencies of the two transmitters are widely separated, the problem can be easily overcome by installation of a *suckout* filter in the offending transmitter's transmission line. (The filter, of course, would be tuned to the frequency of the second transmitter.) Other methods include use of directional antennas on one or both transmitters to minimize radiation in the plane between the two, physically moving one of the transmitter sites, and reduction of transmitter power by either or both stations.

Intermodulation distortion can also occur within a single transmitter in any nonlinear circuit. This form of intermodulation may be caused by defective components, improper bias, excessive drive, etc.

11-2 What are second-order products?

The application of two signals to any nonlinear device results in the production of not only the original two signals, but new signals composed of the sum and difference frequencies of the original signals. This mixing action is the basis of modulation. The product is

any output signal from such a mixing action. The original signals are first-order products. The output signal representing the sum of the two original frequencies is the second-order product. The same nonlinear device which permits mixing of two input signals also permits just one signal to mix with itself to produce a second-order product of the single input signal. This second-order product can then mix with the original signal to produce a third-order product (the third harmonic). This process can continue indefinitely to generate new harmonics, although they will generally bcome extremely weak at the higher multiples and cannot be detected.

11-3 What is meant by peak envelope power?

Single-sideband (SSB) transmitters are rated in terms of peak envelope power (PEP), which is the average power of the transmitter divided by the fraction of each second that an output is actually produced. Normally, it is considered that the carrier power of an AM transmitter must be twice the PEP of an SSB transmitter for comparable operation. This is somewhat misleading in that the PEP of an SSB is based on a duty cycle of 0.5. (Duty cycle is the fraction of each second that a device is actually producing an output.)

11-4 Define deviation.

In radio work, deviation is usually associated with frequency modulated (FM) receivers and used in phrases such as deviation ratio, rate of deviation, deviation distortion, etc. Deviation itself simply means variation. In FM, the frequency of the audio signal determines the number of times per second (rate of deviation) that the radio frequency changes. The amplitude of the AF signal determines the extent of tank circuit frequency change (amount of deviation). A graph representing the changing tank circuit frequency at an audio rate is shown in Fig. 11-1.

The letters f_r represent the resting frequency of the tank circuit when there is no modulating signal present (in this case $f_r = 100$ MHz). With a sinusoidal sound source of 500 Hz applied (A in Fig. 11-1), the amount of deviation on either side of the resting frequency is 25 kHz and the rate of deviation is 500 Hz.

When the amplitude of the 500 Hz sound source is increased to B (as shown in Fig. 11-1) the rate of deviation remains constant but the amount of deviation increases to 75 kHz. The oscillator frequency now changes from 99.925 MHz to 100.075 MHz.

It is also possible to keep the amount of deviation constant but vary the rate of deviation. In a practical FM transmitter the two

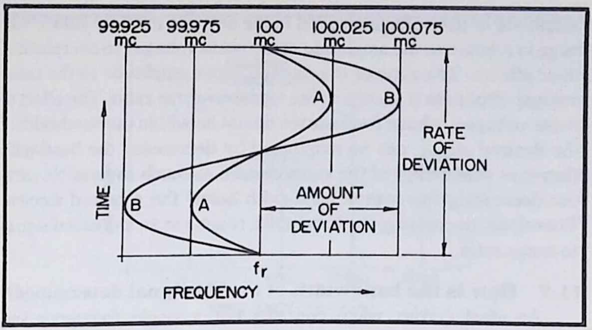


Fig. 11-1. Tank circuit frequency changes.

independent variables, rate and amount of deviation, are continually changing. This occurs because the amplitude (strength) and frequency of the modulating signal are continually changing.

Deviation ratio is the ratio of the maximum frequency deviation to the maximum modulating frequency of an FM system. Deviation distortion in an FM receiver is due to inadequate bandwidth, inadequate AM rejection, or inadequate discriminator linearity.

11-5 What is meant by cross modulation?

Briefly stated, cross modulation is modulation of a desired signal by an undesired signal, for instance, TVI. The term has also been applied to the effect of spurious signals in the front end of sensitive VHF receivers. In most cases, cross modulation can be eliminated by the use of a filter at the receiver to remove the unwanted signal. However, cross modulation can result from the nonlinear mixing of two clean, strong signals by a totally unrelated neighborhood element. The mixing of these two signals may produce another frequency that falls into the IF of a TV or BC receiver. The element causing the nonlinear mixing may be an old rusted pipe or something similar that appears electrically to be a rectifier. It is almost impossible to locate the element causing the trouble, and therefore to cure the problem. Amateurs usually find it expedient to simply change operating frequency when this situation occurs.

11-6 Define the term signal-to-noise (S/N) ratio.

Noise voltages having the same frequencies as the desired signal will receive a proportionate amount of amplification. Thus, the

amplitude of the voltage induced in the antenna must be sufficiently large in relation to the amplitude of the noise voltages to overshadow their effects. The ratio of the desired signal amplitude to the noise voltage amplitude is known as the signal-to-noise ratio. The effect of noise voltages, whose frequencies do not lie within the bandwidth of the desired signal, can be minimized by decreasing the bandwidth (increase selectivity) of the input circuits as much as possible without decreasing the overall bandwidth below the required amount. Therefore, decreasing the bandwidth results in an increased signal-to-noise ratio.

11-7 How is the bandwidth of an AM signal determined?

An ideal carrier wave contains but a single frequency and occupies a very minute section of the frequency spectrum. When the carrier is modulated, sideband frequencies are created above and below the carrier frequency, causing the signal to use up a greater portion of the frequency spectrum. The amount of space in the spectrum required by the signal is called the bandwidth of the signal.

The bandwidth of a modulated wave is a function of the frequencies contained in the modulating signal. For example, when a 100 kHz carrier is modulated by a 5 kHz audio tone, sideband frequencies are created at 95 kHz and 105 kHz. This signal requires 10 kHz of space in the spectrum.

If the same 100 kHz carrier is modulated by a 10 kHz audio tone, sideband frequencies will appear at 90 kHz and 110 kHz and the signal will have a bandwidth of 20 kHz. Notice, that as the modulating signal becomes higher in frequency the bandwidth required becomes greater. From the two examples cited above, it can be seen that at any instant, the bandwidth of an amplitude modulated wave is two times the highest modulating frequency applied at that time. Thus if a 400 kHz carrier is modulated with 3 kHz, 5 kHz, and 8 kHz simultaneously, sideband frequencies will appear at 392 kHz, 395 kHz, 397 kHz, 403 kHz, 405 kHz, and 408 kHz. This signal extends from 392 kHz to 408 kHz and has a bandwidth of 16 kHz, twice the highest modulating frequency of 8 kHz.

11-8 What are sidebands?

A sideband is the frequency band on each side of the carrier frequency which contains the frequencies of the waves produced by the process of modulation.

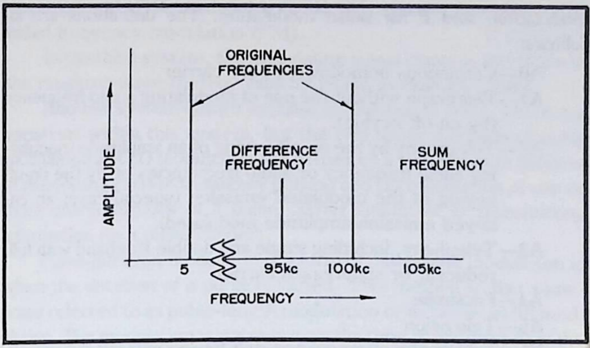


Fig. 11-2. Frequencies present when heterodyning occurs between 5 kHz and 100 kHz.

Assume a 100 kHz rf signal is modulated by a 5 kHz audio signal. The frequencies present can be conveniently represented by a graph of the frequency spectrum. In this graph, shown in Fig. 11-2, each individual frequency is portrayed as a vertical line. The position of the line along the horizontal axis indicates the frequency of the signal, while the height of the line is proportional to the amplitude of the signal. The rf spectrum in Fig. 11-2 shows the frequencies present when heterodyning occurs between frequencies of 100 kHz and 5 kHz.

The sum frequency and the difference frequency are called sideband frequencies. If the modulating frequencies were complex, such as in voice or music (instead of a pure 5 kHz tone), both of the sidebands from 95 kHz to 105 kHz would have complex frequency components. (The modulating frequencies in this example do not exceed 5 kHz.) Therefore, the lower sideband could be composed of almost any frequency between 95 kHz and 100 kHz, while the upper sideband would contain various counterpart frequencies between 100 kHz and 105 kHz.

11-9 Define the various types of emissions and emission symbols used in amateur radio.

The emission symbols consist of a letter and a number, with the exception of phase modulation, which consists of a letter only. The three letters used are A for amplitude modulated, F for frequency

modulation, and P for pulse modulation. The definitions are as follows:

A0—Continuous unmodulated pure carrier.

A1—Telegraph without the use of modulating audio frequency (by on-off keying).

A2—Telegraphy by the on-off keying of an amplitude modulating audio frequency or audio frequencies or by the on-off keying of the modulated emission (special case: an unkeyed emission amplitude modulated).

A3—Telephony, including single and double sideband with full, reduced, or suppressed carrier.

A4—Facsimile

A5—Television

F1—Telegraphy by frequency shift keying without the use of a modulating audio frequency.

F2—Telegraphy by the on-off keying of a frequency modulating audio frequency or by the on-off keying of frequency modulated emission (special case: an unkeyed emission frequency modulated).

F3—Telephony

F4—Facsimile

F5—Television

P—Pulse

11-10 Describe the types and characteristics of the most commonly used modulation systems.

When the modulating signal is combined with the carrier wave in such a manner as to produce new frequencies on either side of the carrier frequency, the process is called modulation. Although a number of systems have been developed to produce modulation, only a few of these systems are commonly used for radio communications. In one such system, the new frequencies which appear as a result of modulation, when added to the carrier frequency, produce a resultant waveform which rises and falls in amplitude. Because of the amplitude variations which occur in the resultant wave as a result of modulation, this system of modulation is called amplitude modulation (abbreviated AM).

In another system of modulation, the modulating signal combines with the carrier in such a way as to cause the frequency of the resultant wave to vary in accordance with changes in the instantane-

ous amplitude of the modulating signal. This system of modulation is called frequency modulation (FM).

In the third system, the modulating signal controls the phase of the resultant wave thereby causing phase modulation (PM).

Another system known as pulse modulation is used. There are variations within this system, but the two major methods of pulse modulation are (1) modulation of a carrier by a pulse train (a process of generating carrier-frequency pulses) and (2) modulation of one or more characteristics of a pulse carrier (methods of transmitting information on a pulse carrier).

Pulse-duration modulaton is a form of pulse-time modulation in which the duration of a pulse is varied. This method is also sometimes referred to as pulse-length modulation or as pulse-width modulation. The modulating wave may vary the time of occurrence of the leading edge, the trailing edge, or both edges of the pulse.

11-11 Draw a diagram of a carrier wave modulated 50% by a sinusoidal wave. Indicate on the drawing the dimensions from which the percentage of modulation is determined.

Figure 11-3 shows examples of modulated AM signals. The top sketch represents a 100% modulated signal. Notice that the section labeled A (at point W) is of constant amplitude; this is the carrier before it has been modulated. Since the carrier and modulating voltages are of equal amplitude, the carrier appears to increase in amplitude until, at point X, the amplitude of the composite waveshape is twice that of the unmodulated carrier. At Z the amplitude has decreased to zero. After 1½ cycles of the modulating signal, the carrier is again unmodulated and of constant amplitude.

In the envelope drawing of Fig. 11-3B the modulating voltage amplitude is only one-half that of the carrier. The composite waveshape does not increase as much as in the first example, nor does the amplitude ever drop to zero.

Figure 11-3C shows an overmodulated carrier. Here, the peak voltage is greater than twice the unmodulated carrier, while the output drops to zero at an earlier point than in example A and remains there for a finite period of time. The envelope in Fig. 11-3C does not resemble the original modulating signal and is thus distorted.

Note these envelope characteristics: A 100% modulated signal consists of envelopes that touch each other even though they drop to

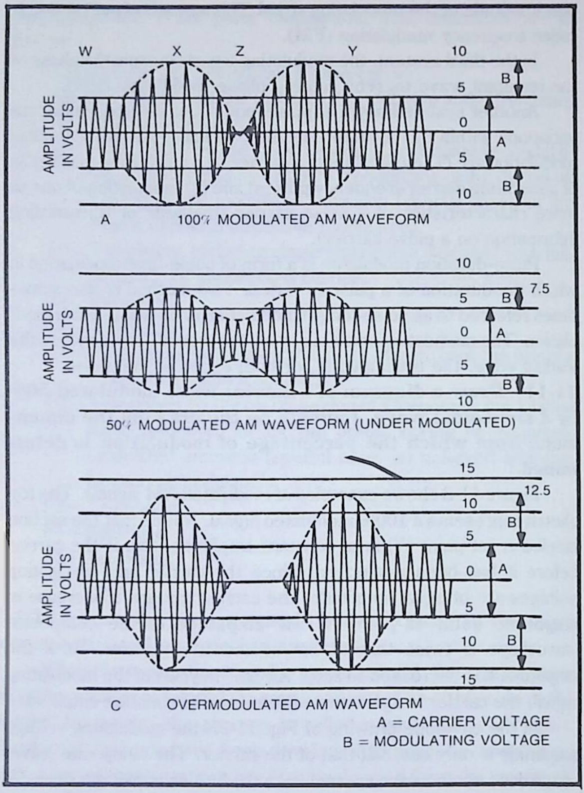


Fig. 11-3. Modulated AM signal examples.

zero. An undermodulated signal does not drop to zero. An overmodulated signal consists of envelopes that drop to zero but which are separated by some distance (time).

11-12 Why does exceeding 100% modulation in an AM transmitter cause excessive bandwidth of emission?

It is first important to understand that some waveforms are more efficient harmonic generators than others. Square waves, in

particular, are very effective in creating harmonic signals. An overmodulated AM signal produces a modulation envelope that is clipped off at the negative half-cycle. This clipped waveform resembles a square wave and is rich in harmonics of the modulating signal. Since the harmonic of a signal is a multiple of the fundamental signal, it stands to reason that an overmodulated signal produces sidebands over a broader range of frequencies than a 100%-modulated rf carrier.

11-13 In a frequency modulation system, (1) discuss the relationship between the percentage of modulation and the number of sidebands, and (2) discuss the difference between phase modulation and frequency modulation.

Percentage of modulation in FM is defined as the percentage of maximum deviation incorporated in a transmitter for a particular type of service. For an FM transmitter with a maximum deviation 75 kHz, 100% modulation occurs when the transmitter deviates the full 75 kHz. When the deviation level falls to 37.5 kHz, the transmitter is being modulated only 50%.

The relationship between the amplitudes of the sidebands and an audio modulating frequency for a modulation index of 2 is shown in Fig. 11-4. The deviation is 30 kHz, with a modulating frequency of 15 kHz. The modulated carrier wave, which is the resultant of the algebraic sum of the carrier and the sidebands, is shown in A with the modulating frequency superimposed upon it. At the positive peaks of the modulation cycle, the instantaneous frequency of the wave is $f_c + f_d$, the frequency peak deviation; whereas, at the negative peaks, the frequency is $f_c - f_d$. The peak-to-peak deviation is therefore 2 f_d. If the carrier frequency is 100 MHz with a frequency deviation of 30 kHz, then the lower deviation limit is 99.97 MHz; and the upper one is 100.03 MHz. There are four sideband pairs whose amplitudes exceed the 1% level, and some of these are greater in amplitude than the center frequency. These are spaced on either side of the carrier frequency, at intervals of 15 kHz, as in Fig. 11-4C, D, E, and F; and each sideband pair has an amplitude as shown in G. The center frequency is reduced in amplitude to 22.4% of the unmodulated value. The first sideband pair, at 99.985 MHz and 100.015 MHz, has an amplitude of 57.7% of the unmodulated carrier value; the second sideband pair, at 99.7 and 100.03 MHz, is 35.3% of the unmodulated carrier; and so on.

Phase modulation and frequency modulation are considered identical by some authorities. Phase modulation is any process that changes the instantaneous frequency of the rf energy already generated at a constant frequency. This is sometimes referred to as phase-angle modulation. All radio modulating processes are based on changing the rf carrier wave in some respect. The variation normally is directly proportional to the instantaneous value of the modulating voltage. When the instantaneous frequency of the carrier is varied in a direct relation to the modulating wave, the result is frequency modulation. If the instantaneous phase of the carrier is varied by an electrical angle directly proportional to the instantaneous modulating voltage, phase modulation is obtained. Varying the carrier frequency also changes the instantaneous phase relation of the carrier frequency to its own fixed unmodulated state. Likewise, varying the carrier phase changes the carrier frequency.

Thus, frequency modulation and phase modulation are basically the same. In fact, frequency modulation is equivalent to phase modulation in which the phase-angle variation is inversely proportional to the modulation frequency. Similarly, phase modulation is equivalent to frequency modulation when it has preemphasis (the signal strength is increased as the audio frequency becomes higher) over the entire range of modulation frequency. An FM signal is one in which the carrier deviation from the resting frequency is proportional to the amplitude of the modulating signal and is independent of the modulating frequency. A pure phase-modulated signal is one in which the carrier deviation is proportional to both the amplitude and frequency of the modulating signal.

11-14 Why is a high percentage of modulation desirable in an amplitude-modulated rf amplifier?

One-hundred-percent modulation allows the greatest amount of power in the intelligence component of the resultant modulated waveform. The carrier/frequency power remains unchanged regardless of the modulation percentage.

11-15 What is the audio frequency range of the human voice?

Audio frequencies extend from 15 cycles per second to 20,000 cycles per second, as shown by the audio-frequency spectrum in Fig. 11-5. The human voice extends from about 87 Hz to 1175 Hz. The violin has a range of from about 200 Hz to 3000 Hz, and the bass

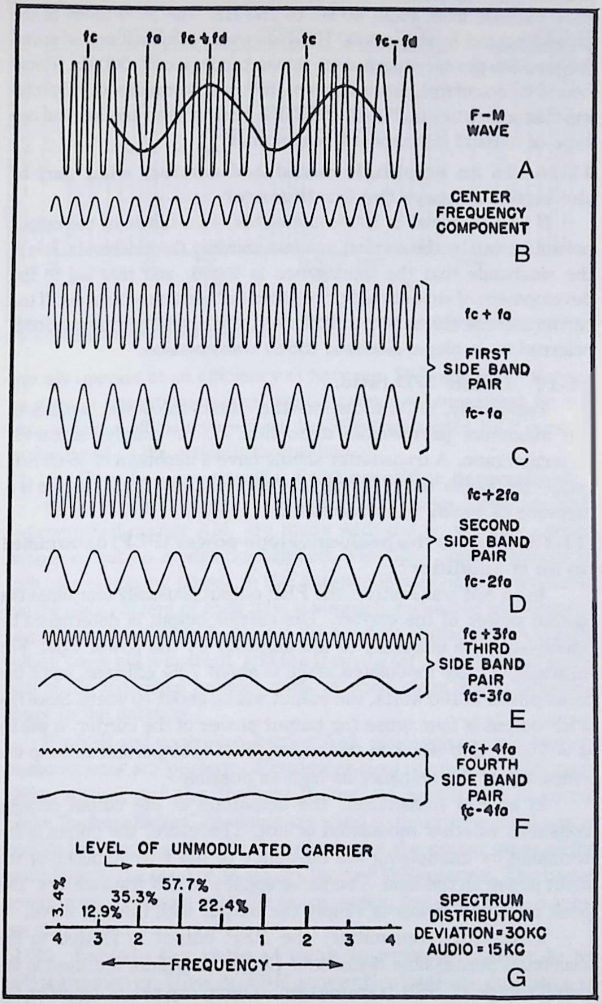


Fig. 11-4. Sideband amplitude and audio modulation relationships.

viola extends from about 40 Hz to 250 Hz. The pure tones of the piccolo extend to about 5000 Hz. However, combinations of sound frequencies produce harmomics that extend up to 20,000 Hz. These combinations of frequencies give to the speech or music the identifying characteristics that distinguish one person from another and one type of musical instrument from another.

11-16 In an amplitude-modulated carrier, what part of the signal conveys the intelligence?

If an AM signal is 100% modulated, two-thirds of the output power is used by the carrier, and one-third by the sidebands. It is in the sidebands that the intelligence is found, and this led to the development of suppressed or reduced carrier transmissions. If the carrier and one sideband are eliminated, the resulting transmission is referred to as single sideband (SSB) transmission.

11-17 Define S/D ratio.

Technically, S/D ratio means the ratio of the power signal S, to the maximum permissible distortion D, or simply, signal-to-distortion ratio. A transmitter should have a minimum of 25 db S/D ratio—the higher the ratio, the less the splatter. The S/D ratio is a measure of quality in a transmitter.

11-18 How is the peak-envelope power (PEP) determined in an rf amplifier?

In an AM transmitter, the PEP output is usually four times the output power of the carrier. The carrier output is determined by multiplying the efficiency of the amplifier by the power input. For example, a plate modulated stage is about 70% efficient, and if the input power is 100 watts, the output will be about 70 watts. Since the PEP output is four times the output power of the carrier, it will be 4×70, or 280 watts in this example. It is important to keep the efficiency of the amplifier as high as possible.

In an FM transmitter, the amplitude at the output remains constant, whether modulated or not. Therefore, the output is determined by multiplying the efficiency of the final amplifier by the input power to the final. The same applies to CW transmitters. The peak envelope power is simply the output with the key down.

In an SSB transmitter, the PEP output is related to the maximum permissible distortion. Linear amplifiers are used in the output stage of SSB transmitters. These classes of amplifier (A, AB_1, AB_2, and B) are not as efficient as the class C amplifier, and

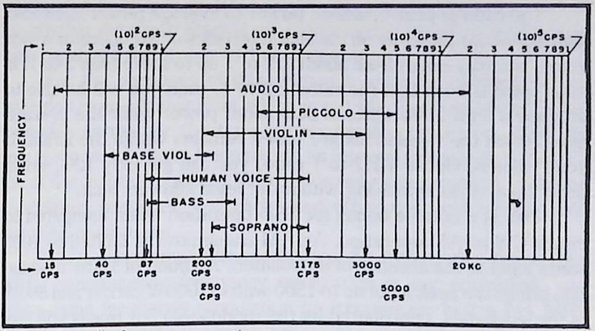


Fig. 11-5. Audio-frequency spectrum.

typically operate at an efficiency of between 20% and 65%. Except for class A operation, power output cannot be measured by the watts-in times efficiency method, so SSB transmitter PEP is rated by the signal-to-distortion ratio method.

11-19 How is power to the final amplifier determined?

All transmitter power measurements, except those for SSB and controlled-carrier AM, are made with the transmitter carrier turned on, but no modulation applied. The plate supply voltage of each tube supplying power to the antenna is measured individually and the plate current of each tube is similarly measured individually. Legal power input to each stage is the product of that stage's supply voltage times place current, and the transmitter's power input is the total of the individual power inputs of each stage which provides power to the antenna.

For SSB and controlled-carrier AM, plate voltage and current measurements are performed during normal operation, with modulation applied, and the "highest flicker" of each meter is noted. These "highest flicker" readings are used to determine legal power input to the stage, and as in the other case the power input of the transmitter is the total of all stages feeding the antenna. The meter needle never keeps up with the voice peaks, but does record average rather than peak power.

11-20 Explain the ratio of peak-to-average power in an SSB transmitter. How do SSB power limitations compare to AM or CW operation?

The ratio of peak envelope power to average power in an SSB signal depends primarily on the characteristics of the operator's own voice, and may range from about 1.2 to 1 up to more than 2 to 1. If your voice is such that the ratio is 2 to 1, then you will be able to produce a legal 2000 watts of peak input power while the average upon which the regulations are based remains within the limits. If your voice produces a 1.2-to-1 ratio, you can get only 1200 watts peak input while remaining within the legal kilowatt limit.

This is a notable bonus for SSB operation when compared to either CW or AM operation. An AM transmitter is limited to 1000 watts input in the absence of modulation. Addition of 100% modulation brings the peak input up to 1500 watts (1000W carrier and 500W in the sidebands, contributed by the modulator) but this is still less than the possible 2000 watts with SSB, especially when you consider that only 250 of the AM rig's 1500 watts are useful and the rest are merely tagging along for the ride.

Despite the possible 4-to-1 advantage in peak power enjoyed by SSB in comparison with CW, the dits and dahs retain the advantage of maximum transmission range. This comes about because CW may be received with only a 50 Hz bandwidth in the receiver, while SSB requires a minimum of 2.7 kHz, some 540 times as great. The 4-to-1 power advantage is canceled out exactly when CW is received with a 675 Hz bandwidth. Cutting that bandwidth in half gives CW a 2-to-1 advantage in effective received signal strength, and each additional halving of bandwidth doubles CW's power advantage. For voice operation, though, no other technique can approach SSB's effectiveness. The nearest competitor is FM.

11-21 What are the characteristics and standards of good quality telephony emissions from amateur radio stations?

Probably the most important characteristic of good quality is the purity and stability of the emission from an amateur station. The FCC rules state that spurious radiation from an amateur station shall be reduced or eliminated in accordance with good engineering practice. Note that spurious radiation may be present, but it shall not be of sufficient intensity to cause interference in receiving equipment of good engineering design and adequate selectivity characteristics.

In the case of A3 emissions, the amateur transmitter shall not be modulated to the extent that interfering spurious radiation occurs, and in no case shall the emitted carrier wave be amplitude-

modulated in excess of 100 percent. Means shall be employed to insure that the transmitter is not modulated in excess of its modulation capability for proper technical operation.

For the purposes of this section a spurious radiation is any radiation from a transmitter which is outside the frequency band of emission normal for the type of transmission employed, including any component whose frequency is an integral multiple or submultiple of the carrier frequency (harmonics and subharmonics), spurious modulation products, key clicks and other transient effects, and parasitic oscillations.

When using amplitude modulation on frequencies below 144 MHz, simultaneous frequency modulation is not permitted, and when using frequency modulation on frequencies below 144 MHz simultaneous amplitude modulation is not permitted. The frequency of the emitted carrier wave shall be as constant as the state of the art permits.

11-22 What causes amplitude distortion?

Amplitude or nonlinear distortion occurs whenever the signal operates over a nonlinear section of the characteristic curve of an amplifier. Amplitude distortion can be caused by the use of improper bias or too large an input signal. Severe amplitude distortion is introduced into the signal if peak clipping occurs as a result of driving a transistor or tube into cutoff, or to the point of grid current flow. Distortion caused by grid current results when the grid current causes a portion of the applied signal to drop inside the source as a result of the high internal impedance of the source.

11-23 What causes frequency distortion?

Frequency distortion is present when some frequency components of a complex signal are amplified more than others. For the most part, frequency distortion is introduced into the signal because of the variable reactance of the coupling capacitor and shunt capacitance. Frequency distortion can be kept to a minimum by insuring that the bandwidth of the amplifier is wide enough to include all significant frequency components of the signal.

11-24 What causes phase distortion?

Phase distortion exists when the phase relationships between the frequency components of the output signal are not the same as in the input signal. An amplifier becomes highly reactive at frequencies far above and below the midband frequencies. At these frequencies

the phase shift becomes nearly 90 degrees. Thus, if high, medium, and low frequency signals are simultaneously applied to the input of an amplifier the midrange frequency will be caused to lag its former phase, and the low frequency signal will be caused to lead with respect to its original phase. Since the three signals have been shifted in time, relative to each other, they no longer produce the same complex waveform when added together in the output of the amplifier.

11-25 List four causes of distortion in a class A audio amplifier.

Four common causes of distortion in class A audio amplifiers are:

1. Excessively high input signal level drives the amplifier beyond the linear portion of its characteristic curve. When this occurs, positive-going input signals drive the amplifier into saturation, and negative-going signals cause the plate current to cut off.
2. Improperly biased amplifier stage. The amplifier must be biased so that its operating point is established in the center of its linear region. If the bias is too positive, the tube or npn transistor will saturate on positive-going signals even though it reproduces well on negative-going signals. If the bias is too negative, the plate (or collector of an npn transistor) current will cut off prematurely on negative half-cycles of the input signal even though the positive half-cycles are reproduced properly.
3. Impedance mismatch between the amplifier stage and its load. Maintaining the proper operating point depends on keeping the amplifier stage matched to the load. Biases are established, based on specific input and output values of impedance. When the impedance changes, so does the operating point.
4. Nonlinearity of the output characteristic. This type of problem is indicative of a faulty tube or transistor in the amplifier stage.

11-26 Compare the design and operating characteristics of class A, class B, class AB, and class C amplifiers.

Class A Operation. The class A amplifier is so biased that plate current flows constantly. In Fig. 11-6 point B is the operating

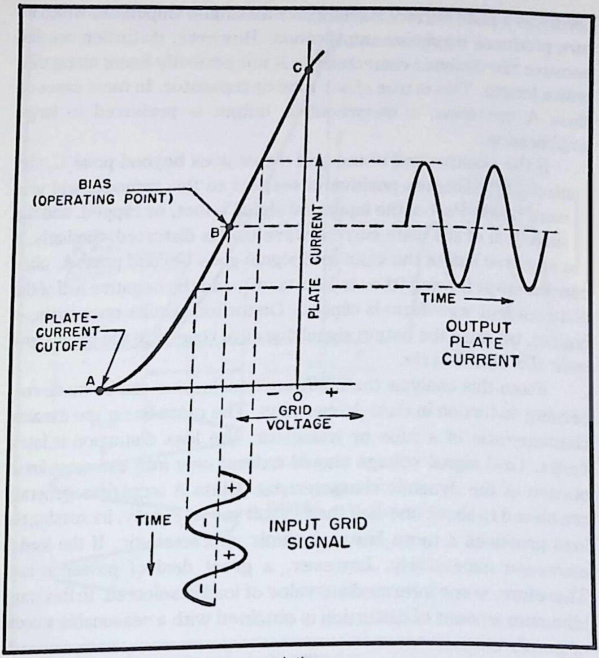


Fig. 11-6. Class A amplifier characteristics.

point and is determined by the bias voltage E_{cc}. The grid signal voltage varies on both sides of the operating point. The output (plate current) waveform is obtained in the figure by extending dotted lines from various points of the input (grid voltage) signal to the dynamic characteristic curve. Note that the plate current waveform is practically undistorted—that is, it closely resembles the input. Minimum distortion takes place because operation occurs along the linear portion of the curve. In addition, the peak-to-peak amplitude of the input grid signal is comparatively small. This prevents it from extending into the nonlinear portions of the curve.

It may seem desirable to have the grid signal extend along the entire length of the characteristic curve from point A to point C. This

produces a plate current waveform of maximum amplitude, which in turn produces maximum amplification. However, distortion results because the dynamic characteristic is not perfectly linear along this entire length. This is true of any tube or transistor. In most cases of class A operation, a distortionless output is preferred to large amplification.

If the positive half of the grid signal goes beyond point C, the control grid becomes positive in respect to the cathode, and grid current flows. Part of the input grid signal is lost, or clipped, and the positive half of the plate current waveform is distorted. Similarly, if the negative half of the input grid signal goes beyond point A, plate current stops flowing (the stage cuts off), and the negative half of the plate current waveform is clipped. Distortion results once again, of course, because the output signal does not resemble the input signal over the entire cycle.

From this analysis the following conclusions can be made concerning distortion in class A operation. The more linear the dynamic characteristic of a tube or transistor, the less distortion it introduces. Grid signal voltage should extend only into the most linear portion of the dynamic characteristic. Class A amplifiers generally are biased to about one-half their cutoff value. Finally, increasing the load produces a more linear dynamic characteristic. If the load is increased excessively, however, a great deal of power is lost. Therefore, some intermediate value of load is selected. In this way a minimum amount of distortion is obtained with a reasonable amount of power output.

The question often arises whether triodes or pentodes should be used for class A operation when vacuum tubes are used. The advantages of using triodes is that their dynamic transfer characteristics usually are more linear and therefore produce less distortion. Pentodes have the advantage of producing a greater power output for a given power input.

Classes of amplifiers are often compared with each other in terms of plate efficiency. Plate efficiency is defined as the ratio of AC power output that is developed across the load to the DC power supplied to the plate. In class A amplifiers the plate efficiency is about 20% or less. This low efficiency is due to the high average value of plate current and consequent high plate dissipation.

Class B Operation. A class B amplifier is one that is biased at or near cutoff (Fig. 11-7). Plate current flows during the positive

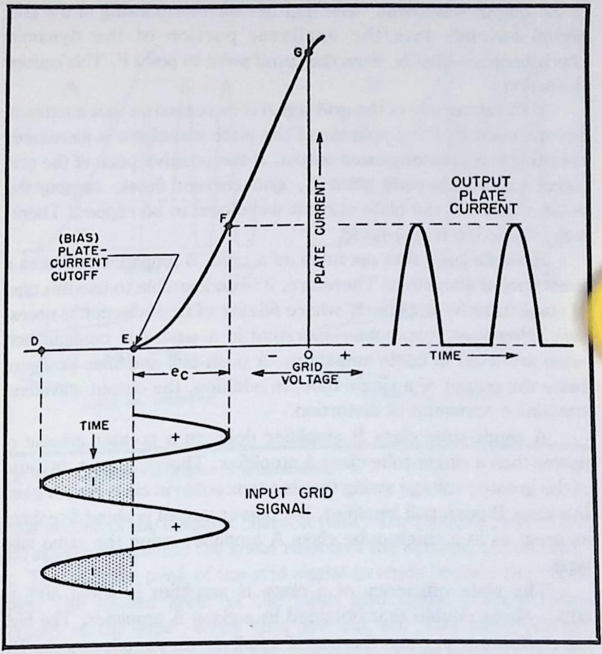


Fig. 11-7. Class B amplifier characteristics.

halves of the input grid signal and stops flowing during the negative half-cycles.

Operating point E equals the bias voltage (E_{cc}), which is established at the point where the amplifier is not conducting. Any positive swings from this point will cause the amplifier to conduct, and any negative swings will keep the amplifier cut off. Plate current starts to flow when the instantaneous value of grid voltage (e_c) rises above the plate current cutoff point. Plate current continues to flow during the positive half of the input grid signal (the unshaded portion of the input grid signal). During the shaded portion of the input signal, the plate current is zero. The shaded portion indicates the part of the input grid signal that has been clipped. Clipping results in severe distortion

of the output waveform. Note that the waveform swing of the grid signal extends into the nonlinear portion of the dynamic characteristic—that is, from the cutoff point to point F. This causes distortion.

If the amplitude of the grid signal is increased so that it extends beyond point F, the amplitude of the plate waveform is increased, resulting in a greater power output. If the positive peak of the grid signal extends beyond point G, grid current flows, causing the positive peak of the plate current waveform to be clipped. Therefore, distortion is increased.

A single tube that operates as a class B amplifier produces a great deal of distortion. Therefore, it is undesirable to use this type of stage in audio amplifiers, where fidelity of reproduction is necessary. However, two tubes operating in a push-pull configuration often are used in audio amplifiers. A push-pull amplifier produces twice the output of a single tube; in addition, the output waveform contains a minimum of distortion.

A single-tube class B amplifier delivers a greater amount of power than a single-tube class A amplifier. This is, in part, because of the greater voltage swing that is permissible in class B operation. In a class B push-pull amplifier, the power output is about five times as great as in a single-tube class A amplifier using the same tube type.

The plate efficiency of a class B amplifier is about 40% to 60%—about double that obtained in a class A amplifier. The high plate efficiency permits the use of small power supplies for the DC operating potentials. Sometimes the fluctuating output current of a class B amplifier is unintentionally coupled into the power source, causing irregularities in the DC operating potentials. When this happens, additional filter circuits are needed.

Class AB Operation. An amplifier that operates in the region between class A and class B is called a class AB amplifier. In a class AB amplifier, the plate current flows for more than one-half cycle but less than the entire cycle of input grid signal. Class AB operation may be subdivided into classes AB_1 and AB_2. The subscript numeral 1 indicates that grid current does not flow during any part of the input cycle. The subscript numeral 2 indicates that the grid current does flow during some portion of the input cycle.

Class AB_1 operation is shown in sketch A of Fig. 11-8. The operating point (H) is located between plate current cutoff and the

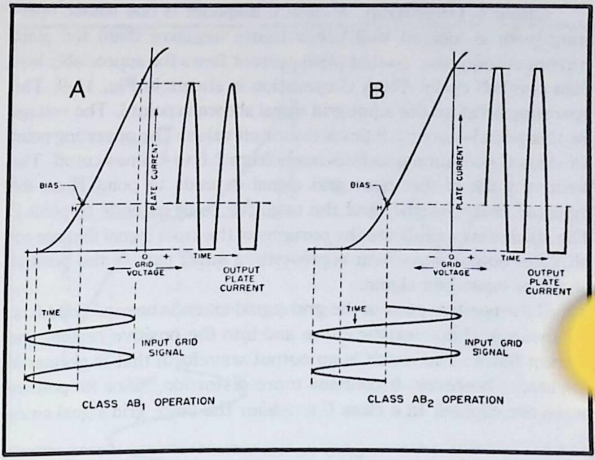


Fig. 11-8. Class AB amplifier characteristics.

linear portion of the dynamic characteristic. The positive peak of the grid signal extends into the linear region of the dynamic characteristic. The negative peak of the grid signal extends beyond the cutoff point. The shaded areas of the input grid signal indicate those portions of the input signal that are cut off. The plate current waveform is distorted by the clipping action of the negative peaks.

Class AB_2 operation is illustrated in sketch B of Fig. 11-8, with the same operating point (H) as shown in sketch A. In class AB_2 operation the peak value of grid signal exceeds the fixed bias of the tube. The positive peaks of input grid signal extend into the positive region of grid voltage. This causes grid current to flow. Just as in class AB_1 operation, the negative input peaks make the grid go beyond the cutoff point.

Clipping is much greater in class AB_2 operation than in AB_1 However, because of the greater grid voltage swing in class AB_2 operation, a greater output exists. The plate efficiency in AB_1 operation is somewhat greater than in AB_2. Compared with class A, class AB operation produces more distortion, more power output, and a greater plate efficiency.

Class C Operation. A class C amplifier is one whose operating point is located well below (more negative than) the plate current cutoff point, so that plate current flows for appreciably less than one-half cycle. Class C operation is shown in Fig. 11-9. The operating point for the input grid signal shown in point J. The voltage for this point is about 1.5 times the cutoff value. The operating point for class C operation usually is made from 1.5 to 4 times cutoff. The positive peak of the input grid signal extends to point K on the dynamic characteristic, and the negative peak extends to point I. The shaded areas indicate the portions of the input signal that are cut off. The output waveform represents a small part of the positive peaks of input grid signal.

If the positive peak of the grid signal extends beyond point L on the dynamic characteristic curve and into the positive region, grid current flows. The result is an output waveform that is greater in amplitude; however, it contains more distortion, since its positive peaks are clipped. In a class C amplifier the large grid signal swing

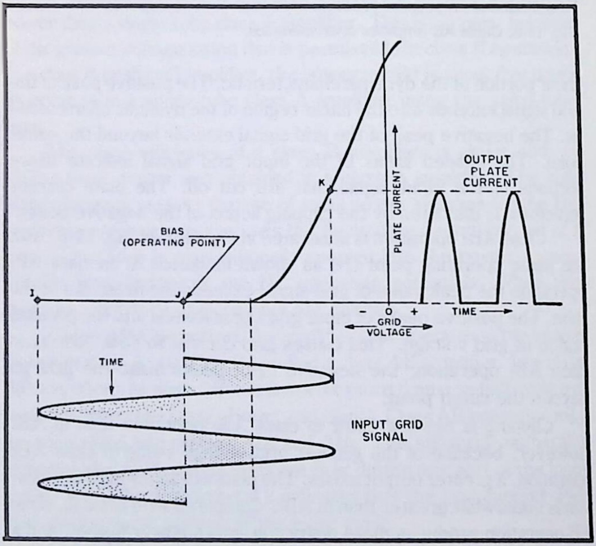


Fig. 11-9. Class C amplifier characteristics.

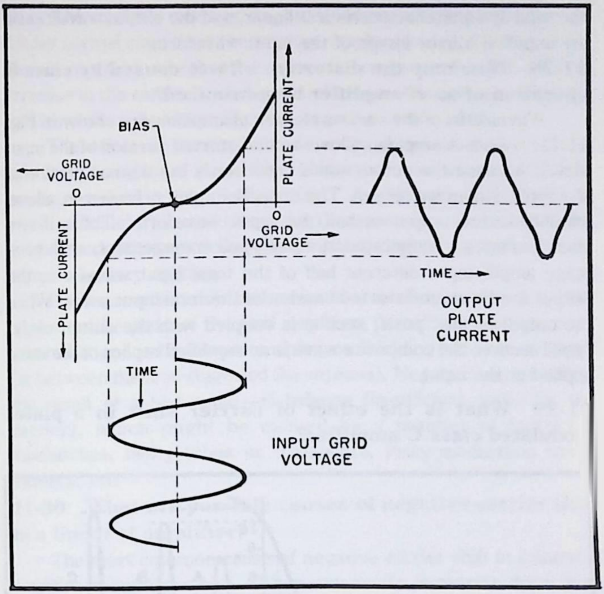


Fig. 11-10. Cutoff bias effect on class B push-pull amplifier.

produces a greater power output as compared to classes A, B, and AB.

Class C amplifiers generally are used as rf amplifiers, where a large power output and a high plate efficiency are often desired. The plate efficiency of a class C amplifier is usually 60% to 80%. The high distortion of a class C stage is overcome by the flywheel effect of tuned circuits.

11-27 Why is it inadvisable to bias class B push-pull audio-frequency amplifiers right at plate current cutoff?

If exact cutoff bias were used, distortion would occur, as shown in the characteristic curve of Fig. 11-10. Here the resultant characteristic has an S-shape that causes severe distortion of the plate current waveform. The bias point ties the individual dynamic curves together. Thus, when each amplifier is biased slightly above cutoff,

the total dynamic characteristic is linear, and the output waveform is an amplified mirror image of the input waveform.

11-28 How may the distortion effects caused by class B operation of an rf amplifier be minimized?

Waveforms of the various classes of amplifier are shown in Fig. 11-11. A class A amplifier allows an undistorted version of the input signal, because the output signal represents but a small portion of the applied input waveform. The class B amplifier, however, allows an undistorted output of half the input waveform. Thus, if two class B stages are operated in a push-pull arrangement, with each stage amplifying a different half of the total input waveform, the output can be an undistorted version of the total input wave. When the output of the "push" section is coupled with the outupt of the "pull" section, the composite wave is an amplified replica of the wave applied at the input.

11-29 What is the effect of carrier shift in a plate-modulated class C amplifier?

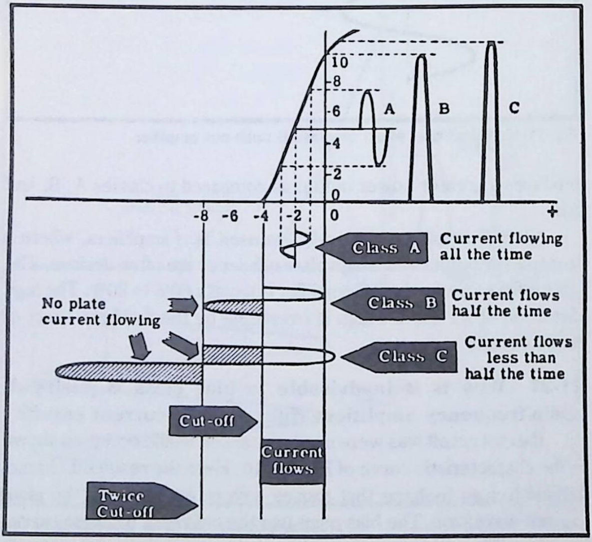


Fig. 11-11. Waveforms for various classes of amplifiers.

Carrier shift is the name for a condition that results in a change in an AM carrier's average amplitude when modulation is applied. Under normal conditions the average amplitude of an AM signal will remain constant, whether the carrier is being modulated or not. An increase in the carrier's average amplitude is referred to as positive carrier shift: a decrease is called negative carrier shift.

The effect of carrier shift depends on whether the shift is positive or negative. A positive shift results in signal distortion, spurious radiation, and "splattering." A negative shift results in weak or "mushy" sound (distortion), antenna resonance instability (with concomitant spurious radiation) and, depending on the caus some frequency shifting.

Positive carrier shift is the result of an excessive audio sig applied to the plate of the final amplifier, parasitic oscillation, poo neutralization, and improper coupling or shielding between rf stages (or between the final stage and the antenna). Negative carrier shift is the result of a bad audio—rf balance (insufficient audio for the carrier), which might be caused by a number of factors—mismatches, faulty tubes or transistors, lossy modulation transformers, etc.

11-30 What are possible causes of negative carrier shift in a linear rf amplifier?

The most common cause of negative carrier shift in a linear rf amplifier is improper bias. Other causes are excessive drive from the exciter stage, improper tuning of the linear's input or the exciter's output (resulting in an improper resistive load for the exciter), and off-resonance operation of the linear amplifier.

11-31. The instantaneous envelope power in a modulated signal is

- **A. inversely proportional to the square of its average amplitude.**
- **B. equal to three times the instantaneous amplitude of the signal.**
- **C. directly proportional to the square of the modulated signal amplitude at every instance.**
- **D. inversely proportional to one-half of the modulated signal amplitude.**
- **E. independent of the amplitude of the modulated signal but dependent upon the rms value.**

Answer: *C*.

[illegible]

... the result of a bad ... supply, which might be caused by ... modulation, leaky tubes or ... transformers, etc.

11-20. What are possible causes of negative carrier shift in a linear rf amplifier?

The most common cause ... amplifier is improper ... [illegible]

11-21. The instantaneous envelope power in a modulated signal is:

A. inversely proportional to the square of the average ...
B. equal to three times the instantaneous ... amplitude ...
C. directly proportional to the square of the modulated signal amplitude ... instantaneous ...
D. inversely proportional to the ... of the modulated signal amplitude.
E. independent of the amplitude of the modulated signal but dependent upon the ... value.

Answer: C.

Chapter 12

Radio Phenomena

This section deals with wave propagation, primaily the effect the ionosphere has on radio waves. We will study this area in detail, but you are also encouraged to review the data contained in the Novice section of this book. You should be thoroughly familiar with the Element 2 (Novice) study questions as well as the Element 3 (General, and Technician) study questions contained herein before you take the FCC test.

12-1 What is meant by the term maximum usable frequency? How does it differ from the critical frequency?

If a radio wave is being transmitted in an upward direction, and its frequency is gradually increased, a point will be reached where the wave will not be refracted sufficiently to curve its path back to the earth. Instead, these waves continue upward to the next layer where refraction continues. If the frequency is sufficiently high, the wave will penetrate all layers of the ionosphere and continue on out into space. The highest frequency which will be returned to earth when transmitted vertically under given ionospheric conditions is called the critical frequency.

In general, the lower the frequency, the more easily the signal is refracted; conversely, the higher the frequency, the more difficult is the refracting or bending process. Figure 12-1 illustrates this point.

We see that the 1-MHz signal is refracted back to the earth at a different location than the 20-MHz signal. The distance between the

transmitting antenna and the point at which the wave returns to earth depends on the angle of propagation in the ionosphere, which in turn depends on the freuency. The highest frequency which is returned to earth at a given distance is called the *maximum usable frequency* (MUF).

Whereas the critical frequency is the highest frequency that will be returned to earth, the maximum usable frequency is the highest frequency that will be returned to earth *at a given distance*.

12-2 Define the term virtual height.

One of the most frequently used methods of long distance transmission is by the use of the sky wave. Sky waves are those waves radiated from the transmitting antenna in a direction that produces a large angle with reference to the earth. The sky wave has the ability to strike the ionosphere and be refracted back to ground. But when the sky wave strikes the ionosphere, it is not sharply reflected as light in a mirror—instead it is bent as it penetrates the ionosphere in a continuous fashion, until it emerges from the ionosphere on its way back to earth.

After the wave leaves the transmitting antenna and before it strikes the ionosphere, it travels in a straight line. It also travels in another straight line on its way back to the earth after it leaves the ionosphere. If we were to project these two straight lines into space, they would meet at some imaginary point, possibly even beyond the ionospheric layer. That point is referred to as the *virtual height* of the ionosphere.

12-3 What are the D and E layers in the ionosphere?

Different densities of ionization at different heights make the ionosphere appear to have layers. Actually there is thought to be no sharp dividing line between layers, but for the purpose of discussion a sharp demarcation is indicated.

The ionized atmosphere at an altitude of between 40 and 50 miles is called the D layer. Its ionization is low and it has little effect on the propagation of radio waves except for the absorption of energy from the radio waves as they pass through it. The D layer is present only during the day. Its presence greatly reduces the field intensity of transmissions that must pass through daylight zones.

The band of atmosphere at altitudes between 50 and 90 miles contains the so-called E layer. It is a well-defined band with greatest density at an altitude of about 70 miles. This layer is strongest during

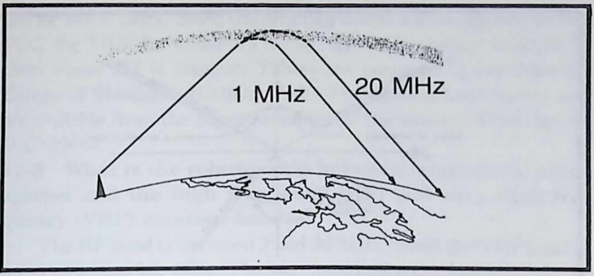


Fig. 12-1. The higher the frequency, the higher the degree of difficulty of refraction.

the daylight hours and is also present but much weaker at night. The maximum density of the E layer appears at about noon local time.

The ionization of the E layer at the middle of the day is sometimes sufficiently intense to refract frequencies up to 20 MHz back earth. This action is of great importance to daylight transmissions distances up to 1500 miles.

12-4 Define the sporadic-E layer.

In addition to the layers of ionized atmosphere that appear regularly, erratic patches of ionized atmosphere occur at E-layer heights in the manner that clouds appear in the sky. These patches are referred to as sporadic-E ionizations. They are often present in sufficient number and intensity to enable good VHF radio transmission over distances not normally possible.

Somtimes sporadic ionizations appear in considerable length at varying altitudes and actually prove harmful to radio transmissions.

12-5 What is the aurora effect?

The aurora is thought to be a collection of ions trapped in the earth's magnetic field, and usually associated with ionospheric storms. During these storms, low frequency communication is sometimes disrupted completely, but VHF communication is often enhanced. It has been found that the aurora borealis will reflect these VHF signals, enabling long-range communication on the high frequencies. This reflection is known as the *aurora effect.*

12-6 What is a ground-reflected wave?

The ground-reflected wave is that portion of the space wave which is reflected from the surface of the earth. The intensity with

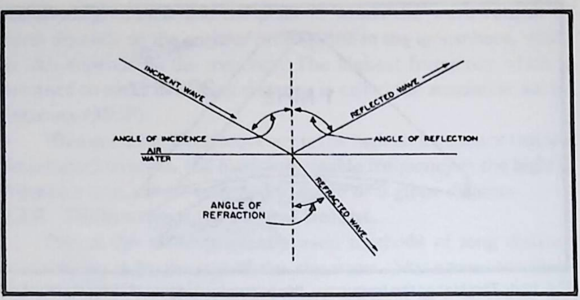


Fig. 12-2. Wave relationships.

which the wave is reflected is dependent upon the coefficient of reflection of the surface which it strikes, and the angle of incidence. The relationship between the direct wave and the ground reflected wave is shown in Fig. 12-2.

To further understand the action of this reflection, consider the diagram in Fig. 12-3. This diagram shows that the reflection of light and the reflection of electromagnetic energy occur in much the same way. Although the angle of incidence is equal to the angle of reflection, there is a change in the phase of the incident and reflected wave, as seen by the difference in the direction of polarization. The incident and reflected waves are 180 degrees out of phase. It is obvious that the ground-reflected wave may cause a decrease in the intensity of the direct wave when they both arrive at the receiving antenna.

12-7 How is the maximum usable frequency determined?

Because of the variations in the critical frequency, nomograms and frequency tables have been prepared that predict the maximum usable frequency (MUF) for every hour of the day for almost every locality in which transmissions are made.

Nomograms and frequency tables are prepared from data obtained experimentally from stations scattered all over the world. All this information is pooled, and the results are tabulated in the form of long-range predictions that remove most of the guess work from radio communication.

With the nomograms and frequency tables, amateur radio operators simply check the highest band that they are equipped to

use for DX activity. Since transmitting bands are designated by the FCC, the MUF for amateurs is the highest frequency available to them where DX is present. Tables are prepared by the National Bureau of Standards (Central Radio Propagation Laboratory) and are available from the Superintendent of Documents, Washington, D.C. 20402.

12-8 What is the relationship between ionospheric propagation and the high frequency (HF) and very high frequency (VHF) amateur bands?

The HF band is between 3 and 30 MHz, while the VHF band is between 30 and 300 MHz. The increased ionization during the day of the ionosphere is responsible for several important changes in sky wave transmission. It causes the sky wave to be returned to the earth nearer to the point of transmission. The extra ionizatio increases the absorption of energy from the sky wave. If the wa travels a sufficient distance into the ionosphere, it will lose all of i energy. The presence of the F_1 and E layers with the F_2 layer make long range high frequency communications possible, provided the correct frequencies are used.

In the 3 to 7 MHz frequency band, good sky wave return is obtained at almost any angle of radiation from the transmitting antenna. High angle radiation into the ionosphere can be used for moderate ranges, but low angle radiation should be used for long distance communications.

When operating in the 7.0 to 7.3 MHz amateur band, you may find that for short to moderate distances, the angle of radiation

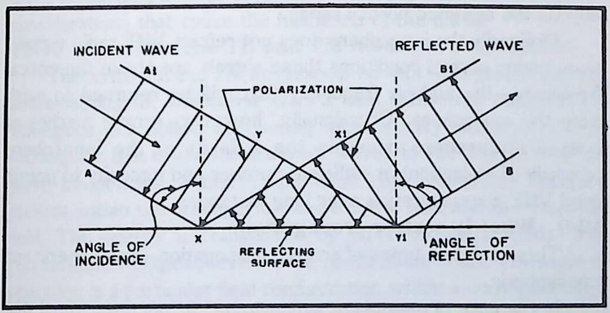


Fig. 12-3. Polarization changes in reflected waves.

should be from 45° to 30°. The lower angle should be used for long distance communication. Higher radiation angles can be used to overcome variations in ion density during peaks of sunspot activity.

The amateur bands between 14.0 and 29.7 MHz are not useful for short distance, sky-wave transmission. The maximum useful angle when operating on 14 MHz is about 30°. As the frequency is increased to 28 MHz, the angle of propagation should be decreased to 10°. Above 28.5 MHz, an angle of less than 10° should be used.

In general, VHF radio waves follow approximately straight lines, and large hills or mountains cast a radio shadow over these areas in the same way that they cast a shadow in the presence of light rays. A receiver located in a radio shadow will receive a weakened signal and in some cases, no signal at all. Theoretically, the range of contact is the distance to the horizon, and this distance is determined by the heights of the two antennas. However, communication is sometimes possible many hundreds of miles beyond the assumed horizon range.

Unusual ranges of VHF contacts are caused by abnormal atmospheric conditions a few miles above the earth. Normally, the warmest air is found near the earth's surface. The air gradually becomes cooler as the altitude increases. Sometimes unusual situations develop where warm layers of air are found above cooler layers. This condition is known as temperature inversion.

When a temperature inversion exists, the amount of refraction (index of refraction) is different for the particles trapped within the boundaries than it is for those outside them. These differences form channels or ducts that will conduct the radio waves many miles beyond the assumed normal range.

Ordinarily the ionosphere does not refract VHF radio signals, since under normal conditions these signals are above the critical frequency—the highest frequency that will be returned to earth from the ionosphere. Occasionally, however, erratic patches of ionized atmosphere occur in the E-layer of the ionosphere (sporadic-E ionization) in sufficient number and intensity to permit good VHF communication over long distances.

12-9 What is scatter propagation?

There are two types of scatter propagation—ionospheric and tropospheric.

In the case of *ionospheric propagation*, it has been found that distances of from 600 to 1200 miles can be reached on frequencies

well above the maximum usable frequency, depending upon transmitter power and directivity. The frequency range for this mode of propagation is 25-60 MHz, and although the signals are weak and fluctuate greatly in amplitude from one instant to the next, they are nevertheless dependable for bandwidths of less than 10 kHz. Scattering occurs in the E-layer of the ionosphere, probably because of ionozation trails left by meteors that continuously enter the ionosphere, or by ionospheric storms or other disturbances. Other characteristics and conditions of ionospheric scatter are:

1. High transmitter power is required.
2. A single hop from the E-layer is the maximum range.
3. A high-gain transmitting antenna must be used.
4. As frequency of the transmitted signal is increased, the strength of the received signal decreases.

Tropospheric scatter propagation does not involve the ionosphere, but is associated with atmospheric conditions. Of particular interest is a phenomenon termed *duct propagation*. Ordinarily the dielectric constant overland decreases linearily with height near the surface of the earth. The dielectric constant at any given time depends primarily on the amount of water vapor present, and in periods of temperature inversion, for example, we may find that a propagation duct exists.

The frequency range for tropospheric scatter propagation is about 40 to 4000 MHz. At locations exceeding 30 miles from the transmitter, the strength of the signal is not dependent on frequency, or on the height of the antenna. What is important is atmospheric considerations that cause the formation of the ducts.

12-10 Describe the TE and TM modes of propagation.

The terms TE and TM are associated with waveguides, and are abbreviations for *transverse electric* and *transverse magnetic*. A waveguide is a hollow conducting tube, usually either circular or rectangular, that is used to transmit waves in the UHF and microwave frequencies. When in operation, two inseparable fields are present within the waveguide—the electric field and the magnetic field. The energy is transferred by electromagnetic fields. The currents and voltages present are a result of the fields. The mode of operation is a particular field configuration within a waveguide. In a transverse electric (TE) mode, all parts of the electric field are

perpendicular to the length of the guide (no electric field is parallel to the direction of travel).

12-11 What is sporadic-E skip?

For some unknown reason, clouds of ionized atmosphere often appear in the E-layer in addition to the normal E-layer of ionization. This thin, unpredictable layer ranges from about 55-80 miles above the earth, and is known as the sporadic-E layer. The ionized clouds which form this layer may be only a few feet wide, or may be several hundred miles across, and may occur either night or day. The amateur radio bands in which skip contacts are made using the sporadic-E layer are usually in the 10-meter band (28.0–29.7 MHz) and the 6-meter band (50–54 MHz), although contacts in the 2-meter band (144–148 MHz) have also been made. Multiple hops of the transmitted signal may occur.

12-12 In what part of the radio spectrum is the ground wave the principal mode of propagation?

A. UHF
B. HF
C. 10–20 MHz
D. Below 30 MHz
E. None of the above

Answer: *E*. (The ground wave is most useful below 5 MHz.)

Chapter 13

Antennas and Transmission Lines

It is possible that some of the areas covered in the Novice class license exam will appear in questions for the General class license. Review both the Novice section as well as the General section of this book before you take the General class exam. This applies particularly to the questions on antennas and transmission lines.

Questions in the Novice section deal with electric and magnetic fields, which are inseparably associated with the flow of electrical current or the motion of a magnetized object. We observed that while the electric and magnetic fields were alternately swapping their energy content to provide motion of the current, some of the energy was lost to the surrounding medium, and this "loss" was known as radiation.

In the FCC exam, you will be asked to define such terms as radiation resistance, parasitic excitation, antenna input impedance, end-effect, and antenna resonance.

You will be asked about types of antennas, such as multi-element arrays and ground antennas, and about antenna characteristics. These characteristics include polarization, directivity, bandwidth, and effective power gain.

The FCC questions on transmission lines may cover such subjects as characteristic impedance, attenuation versus frequency, advantages versus disadvantages of different types of lines, and radiation losses.

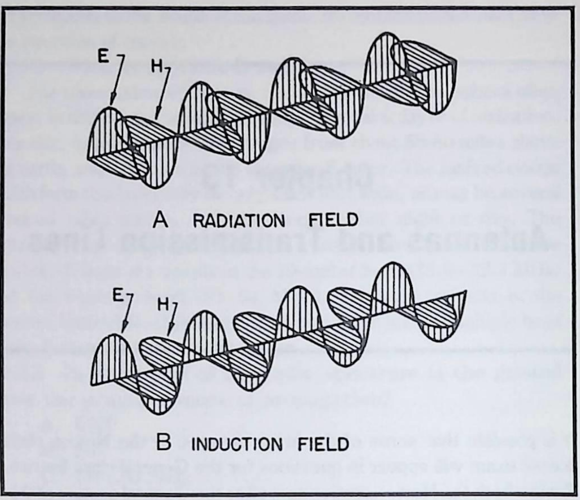


Fig. 13-1. Antenna fields.

13-1 What is meant by the term "radiation resistance"?

Radiation resistance is the ratio of total power dissipated to the square of the effective current for a given antenna, or

$$R = P/I^2$$

where R is the radiation resistance, I is the effective value of antenna current at the feed point, and P is the total power radiated from the antenna.

An understanding of the power dissipation in electromagnetic fields produced by an antenna may be obtained by considering the familiar concepts of power and phase angle in an AC circuit, such as a resonant tank circuit. In an AC circuit true power is equal to voltage times current multiplied by the cosine of the phase angles between them. In an ideal tank circuit each reactive component produces a 90° phase shift between current and voltage. Since the cosine of 90° is zero, the power dissipated over a complete cycle is zero.

An antenna may be considered as a tank circuit. Since the magnetic field is directly proportional to antenna current, it may be used to compute the power dissipated. In the induction field the

electric and magnetic components are 90° out of phase, as illustrated in Fig. 13-1B. Consequently, no power is dissipated by the induction field. Any power delivered to the field during one portion of a cycle must be returned during another portion.

The electric and magnetic components of the radiation field are in phase, as illustrated in Fig. 13-1A, and power is therefore dissipated. The power, which is radiated by the antenna to form the familiar radiation patterns, is comparable to the power dissipated by the resistance of a practical tank circuit. The value of resistance that will dissipate the same amount of power that the antenna dissipates is called radiation resistance. Since a relationship exists between the power dissipated by the antenna and the antenna current, radiation resistance is mathematically defined as noted above.

The radiation resistance varies with antenna length, as shown in the graph of Fig. 13-2. For a half-wavelength antenna the radiation resistance measured at the current maximum (center of antenna) is approximately 73Ω. For a quarter-wavelength antenna the radiation resistance measured at its current maximum is approximately 36.6Ω. These are free space values, that is, the values of radiation resistance that would exist if the antenna were completely isolated so that its radiation pattern would be unobstructed.

For practical antenna installations the height of the antenna affects radiation resistance. Changes in radiation resistance occur because of ground reflections, which intercept the antenna and alter the amount of antenna current flowing. Depending on their phase,

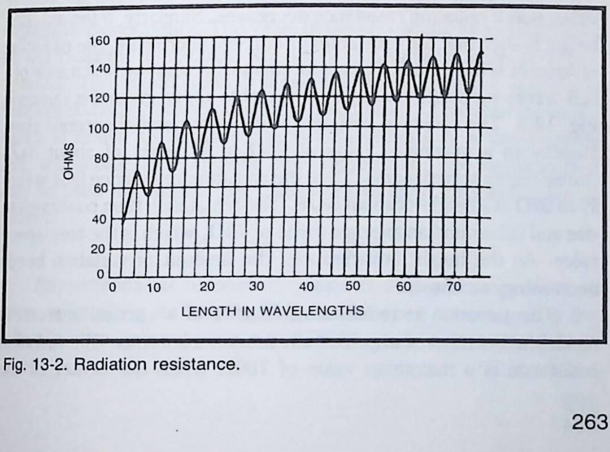


Fig. 13-2. Radiation resistance.

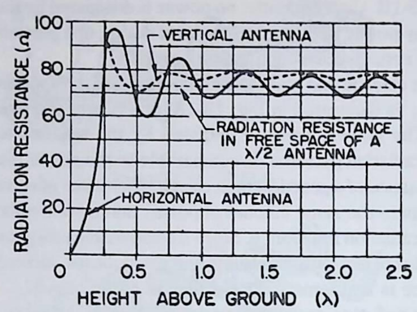


Fig. 13-3. Radiation resistance changes in half-wave antenna.

the reflected waves may increase antenna current or decrease it. The phase of the reflected waves arriving at the antenna, in turn, is a function of antenna height and orientation.

At some antenna heights it is possible for a reflected wave to induce antenna currents in phase with transmitter current, so that total antenna current increases. At other antenna heights, the two currents may be 180° out of phase, so that total antenna current is actually less than if no ground reflection occurred.

With a given input power, if antenna current increases, the effect is as if radiation resistance decreases. Similarly, if the antenna height is such that the total antenna current decreases, the radiation resistance is increased. The actual change in radiation resistance of a half-wavelength antenna at various heights above ground is shown in Fig. 13-3. The radiation resistance of the horizontal antenna rises steadily to a maximum value of 90Ω at a height of about 3λ/8 (three-eights wavelength). Then the radiation resistance falls steadily to 58Ω at a height of about 5λ/8. The resistance then continues to rise and fall around an average value of 73Ω, which is the free-space value. As the height is increased, the amount of variation keeps decreasing, as shown.

The variation in radiation resistance of a vertical antenna is much less than that of a horizontally mounted antenna. The radiation resistance is a maximum value of 100Ω when the center of the

antenna is $\lambda/4$ above ground. The value falls steadily to a minimum value of 70Ω at a height of $\lambda/2$ above ground. The value then rises and falls by several ohms about an average value slightly above the free-space value of a horizontal half-wavelength antenna.

Since antenna current is affected by antenna height, the field intensity produced by a given antenna also changes. In general, as the radiation resistance is reduced, the field intensity increases; an increase in radiation resistance produces a drop in radiated field intensity.

13-2 Define the term "parasitic excitation."

In a beam antenna, the driven element (dipole) is usually referred to simply as the antenna. The other elements in the beam are called parasitic elements, composed of the directors and the reflectors. A director is used to reinforce radiation in a specific direction away from the antenna element when the beam is transmitting, and toward the antenna element when the beam is receiving. A reflector is usually found at the back of the beam to reflect radiated energy toward the antenna element and toward the front of the beam. The length of the element usually determines whether it is a director or a reflector.

The radiation striking these elements causes a certain amount of reradiation, and this is called parasitic excitation.

13-3 What is "antenna input impedance"? What effect does the magnitude of the voltage and current at any point on a half-wave (dipole) antenna in free space have on the impedance at that point?

In the induction field about an antenna, there are inductive and capacitive components. The value of these reactances and the value of the radiation resistance will affect the value of current in the antenna. The combination of a reactive and a resistive opposition renders some impedance value for the antenna. This antenna impedance is similar to the characteristic impedance of a transmission line, and is called the antenna input impedance. The formulas that may be used to compute the values of this input impedance are as follows:

$$Z = E/I \quad Z = R \pm jX$$

Any antenna, at resonance, presents a specific impedance at every point along its length. This can be seen by comparing the voltage and current values distributed along an antenna, as shown in

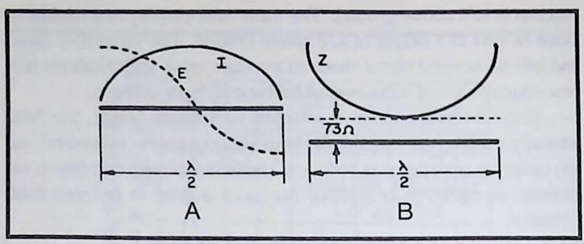


Fig. 13-4. Voltage and current values along an antenna (A); impedance values (B).

Fig. 13-4A. Using the Ohm's law formula for impedance, it can be seen that the highest impedance occurs where current is lowest, and vice versa. Between points of highest and lowest impedance, antenna impedance values follow the curve of Fig. 13-4B.

13-4 Define the term "end effect."

Insulators connected to the ends of a half-wave antenna for support purposes, and even the dielectric effect of air itself, add a certain amount of capacitance to the antenna system. This added capacitance results in a shortening of the actual physical length of the antenna, and is referred to as *end effect*.

The physical length of any antenna is the actual measured length of the antenna from end to end. The physical length (in feet) of a half-wave antenna for a given frequency is derived as follows:

$$\lambda/2(\text{ft}) = \frac{300 \times 3.28 \times 0.95}{2f} = \frac{468}{f}$$

where f = frequency in megahertz. The numbers in the first portion of the equation are derived from the following:

300 = number of millions of meters per second that radio waves propagate
3.28 = number of feet in one meter
0.95 = end-effect factor

The formula is sufficient for wire antennas at frequencies up to 30 MHz. However, it has been found that when a quarter-wavelength antenna is to be used, the end-effect factor is closer to

0.97 of the electrical wavelength. The reason for the different factor is that no insulators are used with quarter-wavelength antennas as these antennas are usually self supporting.

13-5 What factors determine antenna resonance?

Resonant frequency of an antenna is determined by:

- The physical size of the antenna (or its elements, if it is a beam type)
- The series inductance or capacitance at the feed point

An antenna of the correct length for the operating frequency acts as a resonant circuit and presents a pure resistance to the excitation circuit. (Refer to Fig. 13-5). An antenna having other than resonant length displays both resistance and reactance to the excitation circuit. An antenna slightly longer than a half-wavelength, for example, acts as an inductive circuit. A slightly short antenna "looks" capacitive.

13-6 Discuss the directivity and physical characteristics of the parasitic array and stacked array type of antennas.

The parasitic (or multi-element) array consists of a more or less conventional dipole and a number of additional passive dipoles spaced at uncritical intervals along a boom that bisects the plane of the driven element (dipole). The yagi antenna pictured in Fig. 13-6 shows the configuration of a fairly common form of this array. (The term parasitic is derived from the fact that only one element of the antenna is acutally driven; the other elements are completely passive in nature and serve only to reinforce the signals emanating from or arriving at the antenna.)

The dipole labeled radiator in the drawing is the driven element. The reflector is a solid length of aluminum rod (usually) that is slightly longer than the driven element and placed approximately $\lambda/4$ behind it. Because of its length, the reflector reflects the largest percentage of the radiation striking it. The elements situated on the other side of the driven element are called directors. They are shorter than the driven element and serve to reinforce signals approaching from the driven element, adding to the net gain of the antenna itself.

Parasitic arrays are highly directional, depending on the number of elements, the spacing between elements, and the lengths of the directors. When the directors are all cut to the same size

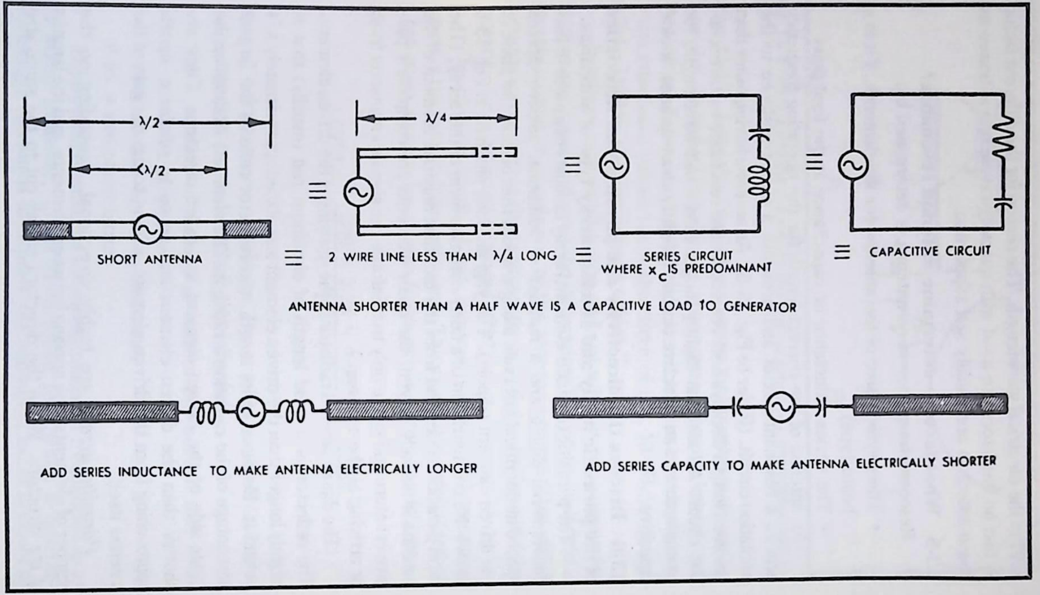


Fig. 13-5. Antenna resonance factors.

(slightly smaller than the driven element), the antenna has a very narrow bandwidth; however, when each director is progressively smaller than the one nearer the radiator, the bandwidth is increased substantially (at the sacrifice of overall gain, of course).

The *stacked array* is an array consisting of at least two ele ments; a radiator and a reflector. If three elements are used, the third element becomes the director and is positioned on a boom as shown in Fig. 13-6. Interestingly, any two such arrays can be stacked to increase the net power gain of a single such array by 3 dB. In practice, the two antennas must be fed and spaced in such a manner that the output signals will be in phase with each other; otherwise, signal reinforcement will not take place and cancellation can occur.

The simplest stacked array is shown in Fig. 13-7. This antenna consists of two dipoles stacked and properly phased. This arrangement is referred to as a lazy H because of the deployed antenna's resemblance to the letter H. The center terminals of each dipole are connected with a parallel wire, as shown. Each conductor of the transmission is attached to this parallel wire at a point midway between the two dipoles to enhance the directivity, and directors may be added to achieve even greater directivity and gain.

Two identical stacked arrays may be connected together (stacked) and phased so that the overall gain of a single array is

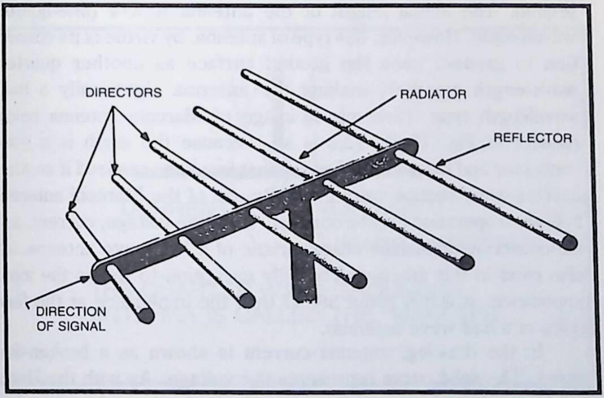


Fig. 13-6. The yagi is a stacked array antenna.

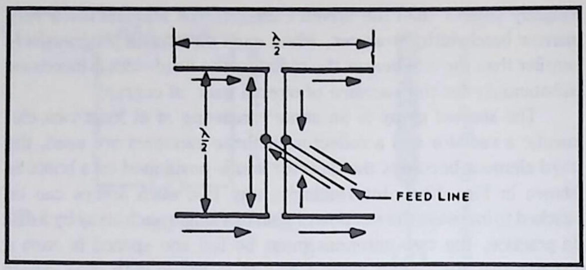


Fig. 13-7. The basic stacked array.

increased by 3 dB. Neglecting losses, each time the effective area of an antenna or array is doubled (by addition of another identical array), the power gain is increased by 3 dB.

13-7 Explain the voltage and current relationships in a quarter-wave grounded antenna.

The grounded quarter-wave antenna is also known as a *Marconi antenna*. The difference between the Marconi antenna and the Hertz (half wave) type is that the Marconi type requires a conducting path to ground, and the Hertz type does not.

A Marconi antenna used as a transmitting element is shown in Fig. 13-8. The transmitter is connected between the antenna and ground. The actual length of the antenna is $\lambda/4$ (one-quarter wavelength). However, this type of antenna, by virtue of its connection to ground, uses the ground surface as another quarter-wavelength member, making the antenna electrically a half-wavelength type. (See mirror image of Marconi antenna below radiator in Fig. 13-8). This is so, because the earth is a good conductor and there is a reflection that would be realized if another quarter-wave section were used. By use of the Marconi antenna, half-wave operation may be obtained. All of the voltage, current, and impedance relationships characteristic of a half-wave antenna will also exist in this antenna. The only exception to this is the input impedance, which is about 36.6Ω (half the impedance at the feed point of a half-wave antenna).

In the drawing, antenna current is shown as a broken-line curve. The solid curve represents the voltage. As with the Hertz antenna, voltage is essentially zero at the feed point and maximum at

the end. Current is maximum at the feed point and diminishes to almost zero at the ends. If the values of voltage (or current) were taken at an infinite number of points along the antenna, the values, when plotted on graph paper, would form a portion of a sine wave.

13-8 Briefly discuss polarization with respect to transmitting antennas.

In describing the principal characteristics of a wave front, the electric field component is taken as the point of reference. For example, the intensity of a radio wave usually is measured in terms of the strength of the electric field, and the orientation of the wave in space usually is described in terms of the direction of wave travel and by the direction of the electric field.

Electromagnetic fields in space are said to be polarized and the direction of the electric field is considered the direction of polarization. As the electric field is parallel to the axis of a half-wave dipole, the antenna is in the plane of polarization. When the half-wave dipole is horizontally orientated, the radiated wave is horizontally polarized. A vertically polarized wave is radiated when the antenna is erected vertically.

For maximum absorption of energy from the electromagnetic fields, it is necessary that a half-wave dipole be located in the plane of polarization. This places the conductor at right angles to the magnetic lines of force that are moving through the antenna, and parallel to the electric lines.

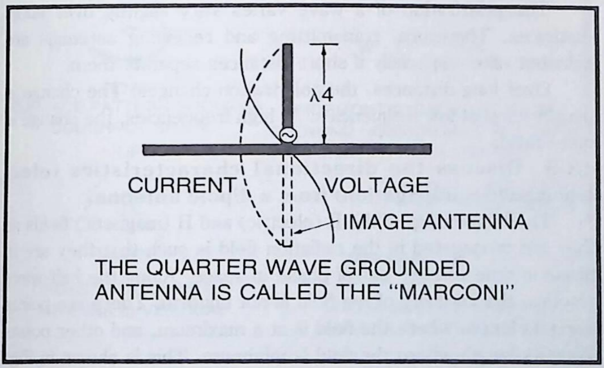


Fig. 13-8. The Marconi antenna.

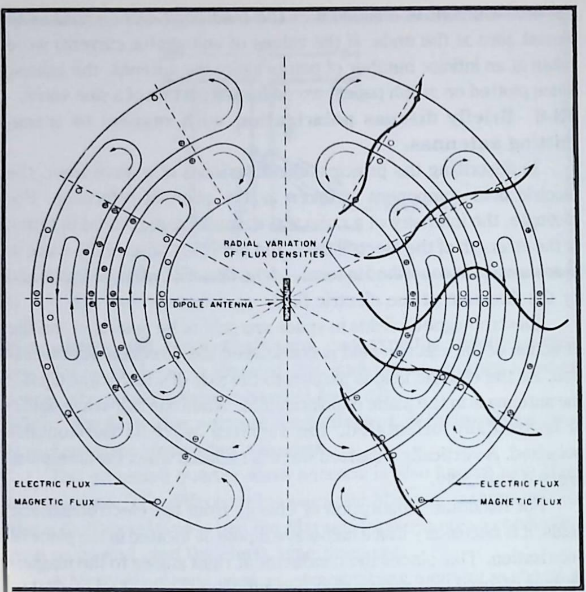


Fig. 13-9. Dipole antenna flux density variations.

The polarization of a wave varies very slightly over short distances. Therefore, transmitting and receiving antennas are oriented alike, especially if short distances separate them.

Over long distances, the polarization changes. The change is usually small at low frequencies. At high frequencies, the change is quite rapid.

13-9 Discuss the directional characteristics (electromagnetic propagation) from a dipole antenna.

The relationship of the E (electric) and H (magnetic) fields as they are propagated in the radiation field is such that they are in phase in time and 90° out of phase in space. Along the half-wave antenna, the intensity of the field is not uniform. There are points along its length where the field is at a maximum, and other points along its length where the field is minimum. This is shown in Fig. 13-9.

The E field is shown as the solid, closed loops that exist on each side of the antenna. The H fields, which are 90 degrees out of phase in space, are shown as the circles that enclose either crosses or dots (to indicate direction). The sine waves that are shown superimposed on the fields indicate the variation in electric flux intensity at various distances and angles away from the antenna.

In a direction perpendicular to the antenna, the fields are strongest. In a parallel direction away from the antenna, that is, off the ends of the antenna, the fields are weakest. For this reason the half-wave antenna is said to be a directional antenna.

Because the current is greatest at the center of a dipole, maximum radiation takes place at this point and practically no radiation takes place from the ends. If this antenna could be isolate completely in free space, the points of maximum radiation woul in a plane perpendicular to the plane of the antenna at its center doughnut-shaped surface pattern is shown in Fig. 13-10A, an horizontal cross section pattern is shown in Fig. 13-10B. Becau circular field pattern is created, the field strength is the same in compass direction.

Theoretically, a vertical dipole in free space has no vertical radiation along the direct line of its axis. However, it may produce a

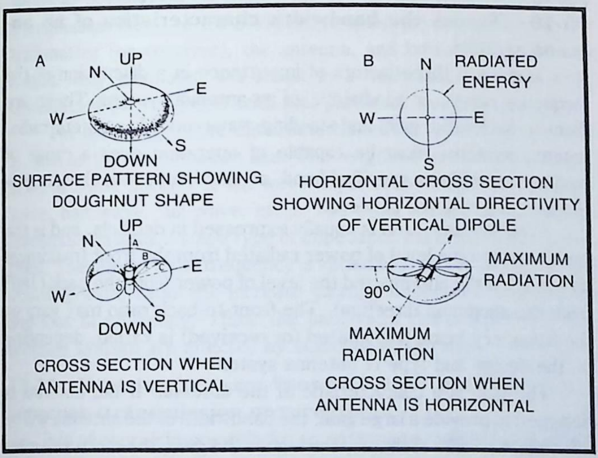


Fig. 13-10. Directional characteristics of a dipole antenna.

considerable amount of radiation at other angles measured to the line of the antenna axis. Figure 13-10C shows a vertical cross section of the radiation pattern of Fig. 13-10A. The radiation along OA is zero; but at another angle, represented by angle AOB, there is appreciable radiation. At a greater angle, AOC, the radiation is still greater. Because of this variation in field strength pattern at different angles, a field strength pattern of a vertical half-wave antenna taken in a horizontal plane must specify the vertical angle of radiation for which the pattern applies.

Figure 13-10D shows half of the doughnut pattern for a horizontal half-wave dipole. The maximum radiation takes place in the plane perpendicular to the axis of the antenna and crosses through its center.

The variation in radiation field intensity about an antenna can be shown graphically by polar diagrams as in Fig. 13-11. Zero distance is assumed to be at the center of the chart indicating the center of the antenna and the circumference of the tangent circles is laid off in angular degrees. Computed or measured values of field strength then may be plotted radially in a manner that shows both magnitude and direction for a given distance from the antenna. Field strengths in the vertical plane are plotted on a semicircular polar chart (not shown in the figure) and are referred to as vertical polar diagrams.

13-10 Discuss the bandwidth characteristics of an antenna system.

There are three factors of importance in a discussion of the frequency range, or bandwidth, of an antenna system. These are front-to-back ratio, gain, and standing-wave ratio. In amateur radio, antenna systems must be capable of operating over a range of frequencies within a specified band, so that bandwidth characteristics become of some concern.

Front-to-back ratio is usually expressed in decibels, and is the ratio between the level of power radiated from the front (maximum direction) of the antenna and the level of power from the back (180° from the maximum direction). The front-to-back ratio may vary as the frequency being transmitted (or received) is varied, depending on the design and type of antenna system.

The gain is a characteristic of the antenna. If the antenna is designed to provide a large gain, the bandwidth of the antenna will be affected. As a rule of thumb, the higher the gain, the more selective the antenna will be, and the narrower the operating bandwidth.

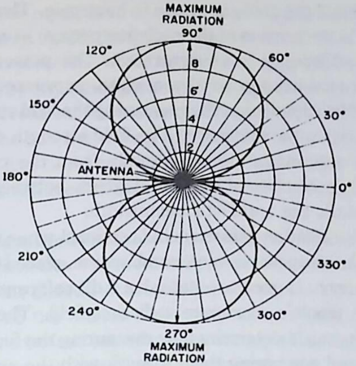


Fig. 13-11. Dipole antenna polar diagram.

The standing-wave ratio will be different at different operating frequencies, and will obviously affect the operating bandwidth of the antenna. Standing-wave ratios are usually discussed along with transmission lines—a 1:1 SWR exists when the impedances at the transmitter (or receiver), the antenna, and both ends of the line match. Any mismatch will result in a decrease of power being transmitted (or received) with that particular antenna system.

The frequency of the signal determines the "cut" of the antenna as well as the transmission line. The length of an antenna is calculated at some portion of the wavelength of the frequency (quarter wave, half wave, full wave, etc.). The same usually holds true for transmission lines if some type of impedance matching device is not used. Therefore, if the frequency is varied beyond certain limits, the standing-wave ratio will increase causing impedance mismatches and loss in efficiency. Thus, the bandwidth characteristics of the antenna system are affected by standing-wave ratios.

13-11 Explain the term "power beam" with respect to antennas (transmission or reception).

It is of course impossible for an antenna to radiate more power than a transmitter provides; however, when an antenna is used in

such a manner as to concentrate a large portion of its energy into a restricted "beam" the antenna is said to have gain. The *power beam* of an antenna is the portion of the radiation pattern in which most of the transmitted energy is concentrated. The power beam of a directional antenna has a power beamwidth, expressed in degrees. This beamwidth is determined by measuring the field strength at the center of the beam for reference. The field strength diminishes as the receiving antenna is moved laterally from the center of the beamwidth. The number of circular degrees between half-power points constitutes the antenna's beamwidth.

A dipole's radiation pattern is bidirectional when it is mounted horizontally. An antenna-receiver combination, placed in the vicinity of such an antenna, is used to establish a 0 dB reference point in the center of the dipole's maximum radiation field. The gain of any beam-type antenna is determined by measuring the field strength at the receiver and comparing this strength with the strength of the field radiated from the dipole. If the antenna at the receiver shows an increase of 3 dB when the beam antenna is used for transmitting, the effective radiated power (ERP) of the transmitting antenna is said to have doubled. This 3 dB gain, it should be emphasized, only occurs in the transmitting antenna's power beam: the field strength at other points in the antenna's radiation pattern will be diminished by more than the amount required to produce the gain in the power beam.

13-12 What is meant by "characteristic impedance," or "surge impedance," of a transmission line? To what physical characteristics is it proportional?

A transmission line typically consists of two parallel conductors spaced a specific distance from each other. The two leads carry current, of course, and so possess the property of *inductance*. And since the two wires are spaced conductors, they also possess the property of *capacitance*. Since the material of which each conductor is made has a specific conductivity, a transmission line possesses the property of resistance. The values of these properties determine the characteristic impedance.

A transmission line of infinite length would be considered as composed of an infinite number of capacitors and inductors. If a voltage were applied to the input terminals of the line, current would begin to flow; it would continue to flow as long as the capacitors and inductors were able to absorb electrical energy. Since there would

be an infinite number of line sections, each having the properties depicted in the equivalent circuit of Fig. 13-12, the current would flow indefinitely. And if the infinite line were uniform, the impedance of any section of the line would be the same as the impedance offered to the circuit by any other portion of the line of the same unit length. Thus, the current would be of some finite value. If the current in the theoretical line and the voltage applied to it were known, the impedance of the line could be determined by application of Ohm's law. This value is referred to as the *characteristic*, or *surge impedance* (Z_0).

In practice, the impedance of a 2-wire line is proportional to the spacing between the wires. Actually, it is a function of the diameter of the wires, the dielectric material separating the two wires, and the conductivity of the wires. However, it is usually fairly easy to estimate characteristic impedance by simply observing the line. The greater the separation between conductors, the higher the impedance. As the diameter increases, the spacing must be increased proportionately to maintain the same impedance values.

Thus, the effect of increasing the spacing of the two wires is to increase the characteristic impedance, because the LC ratio is increased. Similarly, a reduction in the diameter of the wires also increases the characteristic impedance. The reduction in the size of the wire affects the capacitance more than the inductance, for the effect is equivalent to decreasing the size of the plates of a capacitor in order to decrease the capacitance. Any change in the dielectric material between the two wires also changes the characteristic impedance. If a change in the dielectric increases the capacitance between the wires, the characteristic impedance is reduced. The

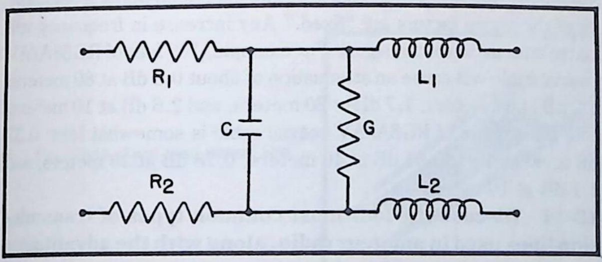


Fig. 13-12. This circuit is electrically equivalent to a transmission line.

characteristic impedance of a 2-wire line with air as the dielectric may be obtained from the formula

$$Z_0 = 276 \log \frac{2D}{d}$$

where D is the spacing between the wires (center to center), and d is the diameter of one of the conductors.

The characteristic impedance of a concentric (coaxial) line with an air dielectric also varies with L and C. However, because the difference in construction of the two lines causes L and C to vary in a slightly different manner, the following formula must be used to determine the characteristic impedance of the coaxial line

$$Z_0 = 138 \log \frac{D}{d}$$

where D is the inner diameter of the outer conductor, and d is the outer diameter of the inner conductor.

13-13 What factors affect attenuation in a transmission line?

A certain amount of attenuation exists in all transmission lines. The factors which have an effect on transmission line attenuation are:

a. The rf frequency
b. The diameter of the inner surface of the outer coaxial conductor
c. The diameter of the center conductor
d. The dielectric constant relative to air
e. The power factor of the dielectric at the rf frequency

In a particular coaxial cable such as might be used in an amateur station installation, we see that with the exception of the frequency, all of the above factors are "fixed." Any increase in frequency will cause attenuation of the signal. For example, 100 feet of RG58A/AV coaxial cable will cause an attenuation of about 0.8 dB at 80 meters, 1.2 dB at 40 meters, 1.7 dB at 20 meters, and 2.6 dB at 10 meters. The attenuation of RG8A/AV coaxial cable is somewhat less: 0.37 dB at 80 meters, 0.51 dB at 40 meters, 0.78 dB at 20 meters, and 1.1 dB at 10 meters.

13-14 Discuss the four most common types of transmission lines used in amateur radio, along with the advantages and disadvantages of each type.

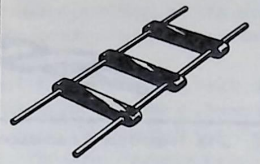


Fig. 13-13. An open wire line, also called a ladder line.

The four most common types of amateur radio transmiss lines are the parallel two wire, the twisted pair, the shielded pair, the concentric coaxial line (rigid and flexible). The use of a partic line depends, among other things, on the applied frequency, t power handling capabilities, and the type of installation.

Two Wire Line. One type of parallel line is the two wire open line illustrated in Fig. 13-13. This line consists of two wires that are generally spaced from two to six inches apart. It is sometimes used as a transmission line between antenna and transmitter or antenna and receiver. An advantage of this type of line is its simple construction. The principal disadvantages of this type of line are the high radiation losses and noise pickup due to the lack of shielding. Radiation losses are produced by the changing fields which are produced by the changing current in each conductor. Some of these lines of force will be radiated from the transmission line in much the same manner as energy is radiated from the sun.

Another type of parallel line is the twin lead or two wire ribbon type. This line is illustrated in Fig. 13-14. This line is essentially the same as the two wire open line, except that uniform spacing is assured by imbedding the two wires in a low loss dielectric, usually

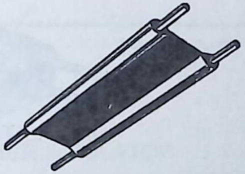


Fig. 13-14. Twin lead ribbon line.

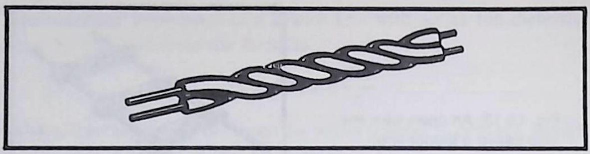


Fig. 13-15. Twisted pair transmission line.

polyethylene. Since the wires are imbedded in a thin ribbon of polyethylene, the dielectric space is partially air and partly polyethylene.

Twisted Pair. The twisted pair transmission line is illustrated in Fig. 13-15. As the name implies, the line consists of two insulated wires, twisted to form a flexible line without the use of spacers. It is not used for high frequencies due to the high losses that occur in the rubber insulation. When the line is wet, the losses increase greatly.

Shielded Pair. The shielded pair, shown in Fig. 13-16, consists of parallel conductors separated from each other, and surrounded by, a solid dielectric. The conductors are contained within a copper braid tubing that acts as a shield. The assembly is covered with a rubber or flexible composition coating to protect the line from moisture or mechanical damage. Outwardly, it looks much like the power cord of a washing machine or refrigerator.

The principal advantage of the shielded pair is that the conductors are balanced to ground; that is, the capacitance between the cables is uniform throughout the length of the line. This balance is due to the grounded shield that surrounds the conductors with a uniform spacing along their entire length. The copper braid shield isolates the conductors from stray magnetic fields.

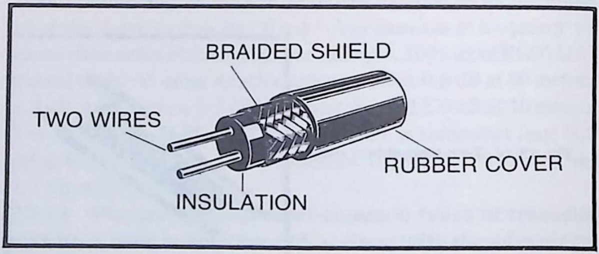


Fig. 13-16. Shielded pair transmission line.

Coaxial Lines. There are two types of coaxial lines: the rigid or air coaxial line and the flexible or solid coaxial line. The physical construction of both types is basically the same, each contains two concentric conductors.

The rigid air coaxial line consists of a wire mounted inside of, and coaxially with, a tubular outer conductor. This line is shown in Fig. 13-17. In some applications the inner conductor is also tubular. The inner conductor is insulated from the outer conductor by insulating spacers, or beads, at regular intervals. The spacers are made of pyrex, polystyrene, or some other material possessing good insulating characteristics and low loss at high frequencies.

The chief advantage of this type of line is its ability to minimize radiation losses. The electric and magnetic fields in the two wire parallel line extend into space for relatively great distances and radiation losses occur. No electric or magnetic fields extend outside of the outer conductor in a coaxial line. The fields are confined to the space between the two conductors, thus the coaxial line is a per fectly shielded line. Noise pickup from other lines is also prevented

This line has several disadvantages: it is expensive to cc struct, it must be kept dry to prevent excessive leakage between th two conductors, and although high frequency losses are somewhat less than in previously mentioned lines they are still excessive enough to limit the practical length of the line.

The condensation of moisture is prevented in some applications by the use of an inert gas, such as nitrogen, helium, or argon, pumped into the line at a pressure of from 3 to 35 pounds per square inch. The inert gas is used to dry the line when it is first installed and a pressure is maintained to insure that no moisture enters the line.

Concentric cables are also made with the inner conductor consisting of flexible wire insulated from the outer conductor by a solid, continuous insulating material (Fig. 13-18). Flexibility may be gained if the outer conductor is made of metal braid.

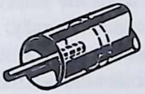


Fig. 13-17. Rigid air coaxial line.

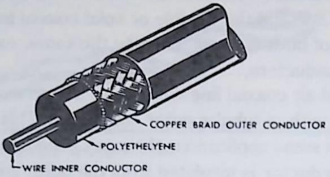


Fig. 13-18. Flexible or solid coaxial line.

13-15. What causes radiation loss in a transmission line? How may these losses be reduced?

The electrostatic and electromagnetic fields that surround a conductor cause losses in transmission lines. The action of the electrostatic fields is to charge neighboring objects, while the changing magnetic field induces an EMF in nearby conductors. In either case, energy is lost.

Radiation and induction losses may be greatly reduced by terminating the line with a resistive load equal to the line's characteristic impedance, and by proper shielding of the line. Proper shielding can be accomplished by the use of coaxial cables with the outer conductor grounded.

13-16 What is meant by "standing waves?" Explain "standing-wave ratio." How can standing waves be minimized?

Standing waves are difficult to explain because they involve a concept that cannot be observed. The theory can be simplified, however, by applying a fairly simple analogy. Suppose, for example, that radio waves were visible under certain conditions of illumination, and had the appearance of a sine wave superimposed on a full-wave antenna. Suppose also that we could strobe our "special illumination source" at a rate that matched the frequency of the signal being generated. Then, when the strobe "light" was aimed at our antenna, we would have the ability of seeing waves as they propagated from the antenna. Ideally, under this condition, the antenna being fed a continuous signal would appear to have a full sine wave superimposed on it that did not move. Such a situation would be equivalent to having a standing-wave ratio of 1:1, which means that a wave is propagated into space for every wave that is fed into the antenna.

If, under this condition of hypothetical observation, the wave did not stand still, a less than ideal situation would be indicated. If the antenna were a shade too long, for example, or if there were a mismatch between the antenna and the transmission line, the wave would not be fully developed across the breadth of the antenna before a new wave tries to enter the antenna. As a consequence, part of the signal (lower in amplitude than the applied signal) would be reflected back toward the transmitter. In a mismatch situation the reflected signal travels back down the line at the same time other waves are antenna-bound. At the generator end (transmitter), another reflection takes place; part of the reduced-amplitude signal is dissipated across the final tank circuit or the antenna-matching network, while a smaller portion of the reflection is rereflected back up the line but out of step (phase) with the original signal. The process is repeated with each wave applied to the transmission line and the reflected components serve to cancel and interfere with the originally applied signal. At peak efficiency there is no reflected signal, and a wave is radiated into space at precisely the same time a new wave is developed across the antenna.

All the wave diagrams in Fig. 13-19 show the relationship that exists between the incident (applied) and the reflected wave in a transmission line that is terminated in an open circuit (the termination is not resistive at the line's characteristic impedance, but rather it is as a transmission line that has been disconnected from the antenna). The dark line shown superimposed on the waveform represents the standing waves. Standing waves are the instantaneous sum of both the incident and reflected waves. In the open transmission line the relationship between the incident and reflected wave is such that they are equal in amplitude and phase at the receiving end. The phase relationships in the figure may appear confusing, but it must be remembered that the indicent wave is moving to the right while the reflected wave is moving to the left. In each of the diagrams shown, the instantaneous sum (standing waves) is plotted using the heavy dark line. In diagrams 2 and 6 the waveforms coincide, and at that point in time, the volatage is zero. If the diagrams are examined further, it is found that at a point one-quarter of the distance from the end and at a point three-quarters of the distance from the same end the voltage is zero at all times. Because of the zero stationary point, the waves are appropriately called "standing waves."

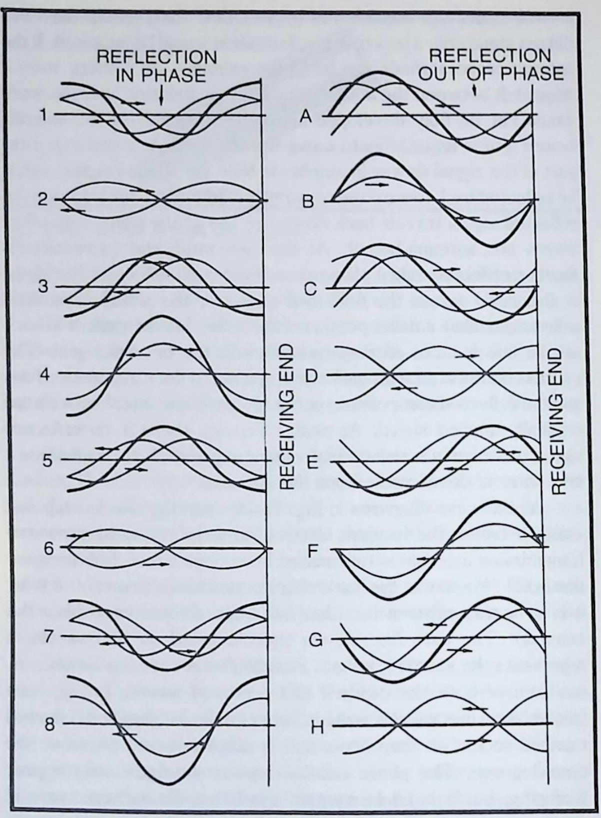


Fig. 13-19. Relationships between applied and reflected waves in a transmission line.

If an AC meter were used and current measurements were taken on the line, the current readings would only be of magntiude and not of polarity. If the values thus found were plotted on a graph, the current curve would appear as the positive-going waves illustrated in Fig. 13-20. This is the conventional picture of standing waves.

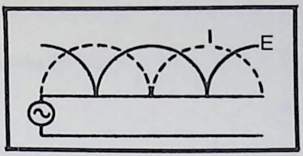


Fig. 13-21. Voltage/current relationships at transmission line termination.

At the end of a transmission line terminated in an open, the current is zero and the voltage is maximum at the terminating end. This relationship may be stated in terms of phase. The voltage and current at the ends of an open-ended transmission line are 90° out of phase. At the end of a transmission line terminated in a short, the current is maximum and the voltage is zero. The voltage and current are again 90° out of phase. These current-voltage relationships are shown in the diagrams of Fig. 13-21. These phase relationships are important because they indicate how the line will act at different points along its length. A transmission line will have points of maximum and minimum voltage as well as points of minimum and maximum current. The position of these points can be accurately predicted if the applied frequency and type of line termination are known.

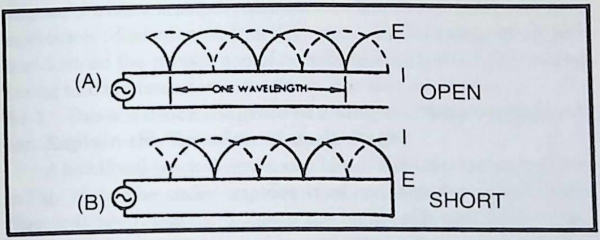
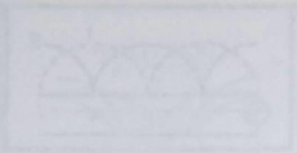


Fig. 13-20. Plot of AC meter indicates only magnitude.

13-17 The ratio of the total power radiated to the square of the current in the antenna is

A. the radiation resistance
B. the power gain
C. the power density
D. the feed point impedance
E. the field strength

Answer: *A*



Chapter 14
Radiocommunication Practices

This chapter will test your knowledge of complete systems as applied to amateur radio. You will be requested to draw block diagrams of a single-sideband transmitter, an amplitude-modulated transmitter, a frequency-modulated transmitter, and a functional diagram of a basic amateur radio station. Questions on how to check modulation, distortion, frequency, etc., are included, along with questions on the proper use of certain test equipment. Areas pertaining to communications receivers are also covered.

14-1 Draw a block diagram of a single-sideband transmitter. Explain the function of each stage.

A functional block diagram of a basic SSB transmitter is shown in Fig. 14-1. The audio amplifier is of conventional design. Audio filtering is not required, because the highly selective filtering that takes place in the SSB generator attenuates the unnecessary frequencies below 300 Hz and above 3 kHz; i.e., those frequencies falling outside the audio communication spectrum. (A voice signal is used only as a convenience for explanation; the input signal may be any desired intelligence signal and may cover all or any part of the frequency range between 100 and 6000 Hz.) The upper limit of the input audio signal is determined by the channel bandwidth and upper cutoff frequency of the filter in the sideband generator. The lower limit of the input audio signal is determined by the lower cutoff frequency of the filter in the SSB generator.

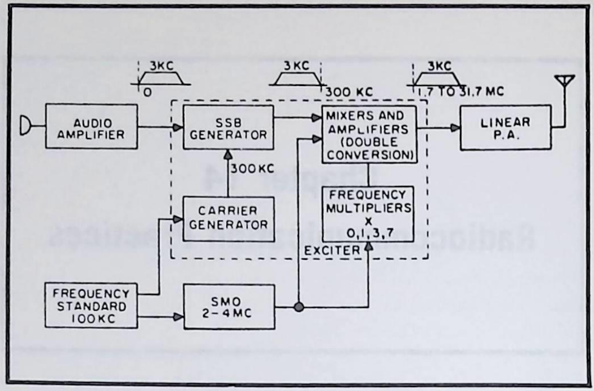


Fig. 14-1. SSB transmitter functional block diagram.

The SSB generator produces the SSB signal at an intermediate frequency (i-f). To produce the SSB signal, a double-sideband (DSB) signal is generated and passed through a highly selective filter to reject one of the sidebands. The SSB signal is generated at a fixed intermediate frequency because highly selective circuits are required. The filter requirements for the filter method of SSB signal generation are met by either crystal or mechanical filters.

The generated SSB signal at a fixed i-f is passed through mixers and amplifiers, where it is converted to the transmitted radio frequency. Two-stage conversion is shown, with the second conversion frequency being a multiple of the first conversion frequency. The frequency conversions required to generate the radio frequency produce sum and difference frequencies as well as higher order mixing products inherent in mixing circuits. However, the undesired difference frequency or the undesired sum frequency, along with the higher-order mixing products, is attenuated by interstage tuned circuits.

Because an SSB system without a pilot carrier demands an extremely stable frequency system, the frequency standard and stabilized master oscillator (SMO) are extremely important. The standard frequency is obtained from a crystal oscillator, with the crystal housed in an oven. Since the stability of the crystal frequency depends directly on the stability of the oven temperature, stable

thermal control of the oven is necessary. This thermal control of the oven is obtained by using heat-sensitive semiconductors in a bridge network. Any variation in the oven temperature is corrected by an imbalance in the control bridge. The carrier generator provides the i-f carrier used to produce the fixed i-f SSB signal, and the SMO provides the necessary conversion frequencies to produce the rf SSB signal. The frequencies developed in these units are derived from (or phase-locked to) the single standard frequency, so that the stability of the standard frequency prevails throughout the SSB system. Choice of the fixed i-f and conversion frequencies to obtain the rf is an important design consideration. Optimum operating frequencies of the various circuits must be considered was well as the control of undesirable mixing products. The use of harmonically related conversion frequencies in the mixer permits a very broa frequency range to be covered with a single 2-4 MHz oscillator– very practical range for obtaining high oscillator stability. Use of t 300 kHz fixed i-f is the optimum operating condition for the filte required in the SSB generator.

The SSB exciter output drives a linear power amplifier to produce the high-power rf signal. A linear power amplifier is required for SSB transmission because it is essential that the plate output rf signal be a replica of the grid input signal. Any nonlinear operation (distortion) of the power amplifier will result in an intermodulation (mixing) between the frequencies of the input signal. This will produce not only undesirable distortion within the desired channel but will also produce intermodulation outputs in adjacent channels.

14-2 Draw a block diagram of an amplitude-modulated transmitter. Briefly explain its operation.

In amplitude modulation the instantaneous amplitude of the RF output signal is varied in proportion to the modulating signal. The modulating signal may consist of many frequencies of various amplitudes and phases, such as the signals comprising speech.

The block diagram of a simple AM radio-telephone transmitter is shown in Fig. 14-2. The oscillator, buffer, and power amplifier serve the same purpose as in a CW transmitter. The microphone converts the audio (sound) input into corresponding electrical energy. The modulator amplifies the audio signal to the amplitude necessary to fully modulate the carrier. The output of the modulator

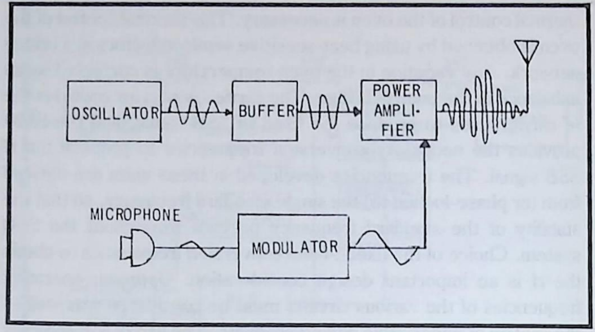


Fig. 14-2. AM radiotelephone transmitter block diagram.

is applied to the power amplifier. The RF carrier and the modulating signal are combined in the power amplifier to produce the amplitude modulated RF carrier output for transmission. In the absence of a modulating signal, a continuous RF carrier is radiated by the antenna.

14-3 Draw a block diagram of a frequency-modulated transmitter and briefly explain its operation.

The block diagram of a typical narrow-band FM transmitter is shown in Fig. 14-3. Oscillations are produced in the crystal-oscillator stage, the output of which is fed to a phase-shift network that supplies the grid voltage of the modulator tubes. The phase of the output voltage of the modulator varies in accordance with the input signal from the microphone. The phase shift is equivalent to a relatively low deviation of the output signal frequency of the modulator stage.

The frequency of the output of the modulator stage is quadrupled in the first multiplier stage, again quadrupled in the second multiplier stage, and doubled in the last multiplier the output of which drives the power amplifier stage, which frequently consists of two beam-power tubes in parallel (depending on power requirements).

14-4 Draw a functional block diagram of a basic amateur radio station.

A block diagram of a basic amateur radio station is shown in Fig. 14-4. The FCC rules and regulations require that means be employed to insure that the transmitter is not modulated in excess of

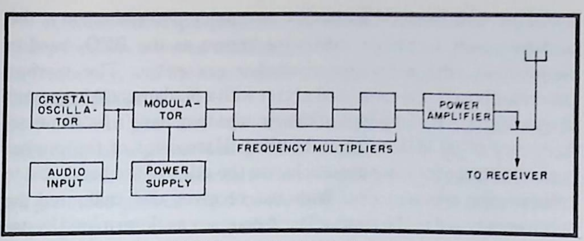


Fig. 14-3. Narrow-band FM transmitter block diagram.

its modulation capability, and in no case shall the emitted AM carrier wave be modulated in excess of 100% (paragraph 97.73). In addition, the licensee of an amateur station shall provide for measurement of the emitted carrier frequency or frequencies and shall establish procedure for making such measurement regularly (paragraph 97.75). This means that the basic amateur radio should consist of a recevier and a transmitter (with suitable power supplies), an antenna system, a telegraph key and/or a microphone, a modulation monitor, and a frequency meter. The latter two items are not required continuously, but are necessary for frequent checks of the operation of the station.

14-5 How is the frequency of the transmitted signal determined?

In amateur radio, it is not necessary that the *exact* operating frequency be known, but that the frequency is inside the limits of the band. Several devices are employed to insure that the operating frequency, including the sidebands, is within limits, since there is no tolerance at the edge of the band.

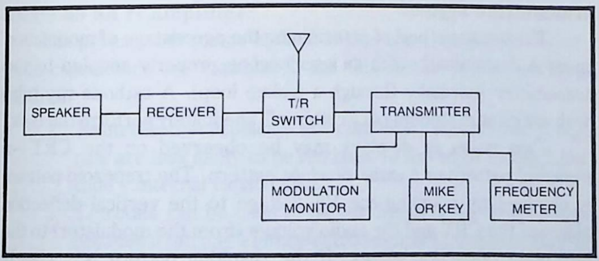


Fig. 14-4. Block diagram of a basic amateur station.

The most common method of frequency determination is the beat frequency oscillator, otherwise known as the BFO, used in conjunction with a *frequency marker generator*. The marker generator is a crystal controlled circuit with a fundamental frequency of usually 100 kHz (although some circuits may have a fundamental frequency of 50 kHz or even 25 kHz). Harmonics of the marker generator frequency are used to locate the edge of the band, and to calibrate the receiver dial. With the receiver dial calibrated, the receiver is tuned to the transmitter frequency as determined by use of the BFO.

Two other methods in common practice are by use of the absorption frequency meter and the dip meter. The absorption frequency meter is a calibrated LC circuit that can be tuned across the band under consideration. A meter is used to indicate when the approximate frequency of the circuit being checked is the same as the frequency of the absorption meter. With this device, RF energy must be present in the circuit under test.

The dip meter, on the other hand, provides its own source of RF energy. As it is tuned across the band under consideration in the proximity of the circuit under test, the meter will indicate the approximate frequency by a change in its reading. The principle of operation of both the absorption frequency meter and the dip meter is that energy will be transferred from one circuit to another when both circuits are in resonance. This transfer of energy can be detected by meter deflection.

Digital frequency meters are available (although unnecessary in amateur radio) which will measure frequency and display the results with extreme accuracy.

14-6 How is the percentage of modulation tested in an AM transmitted signal?

The usual method of determining the percentage of modulation in an AM system is with an oscilloscope properly coupled to the transmitter (normally through a pickup loop). A cathode-ray tube with a minimum amount of circuitry will adequately perform the task.

Two types of displays may be observed on the CRT—a *trapezoid* pattern or a *wave-envelope* pattern. The trapezoid pattern is obtained by coupling the RF voltage to the vertical deflection plates of the CRT and the audio voltage (from the modulator) to the horizontal deflection plates. If the resulting pattern is a clearly defined triangle, the modulation is 100%.

A wave-envelope pattern will be obtained if the horizontal sweep frequency (on an oscilloscope) is set lower than the modulating frequency, and the modulated RF voltage coupled to the vertical deflection plates.

14-7 What precautions must be observed at the input (cathode) of a grounded-grid amplifier?

There are certain factors that must be taken into consideration in a grounded-grid circuit. For example, there is often a problem in isolating the cathode from ground as far as the RF is concerned. This problem may exist (infrequently) even in indirectly heated cathodes, and if so, a pair of RF chokes must be used in the heater leads.

If the cathode is directly heated, two common approaches are used to keep the RF above ground. One method uses the RF chokes as mentioned above, while the other employs an input tank circuit that can be tuned to the proper frequency.

The grounded-grid power stage normally exhibits an input impedance of between 25 and 350 ohms. The input network must be designed to provide the correct impedance match.

14-8 What considerations must be given to line amplifier adjustments?

To prevent distortion of a signal after modulation has been applied, the shape of the modulation envelope must be preserved. A linear amplifier will reproduce at its output an exact replica of the signal applied to the grid (in a tube-type linear). Therefore, the AM driving signal must remain above cutoff on the down peaks, or clipping would occur at that part of the modulation envelope at the zero axis. This can be accomplished by setting the grid bias at or slightly less than cutoff.

14-9 What is the principal advantage of a tetrode over a triode as an rf amplifier?

The primary advantage is the fact that the effects of interelectrode capacitance are minimized; and this results in two ancillary features.

1. Neutralization problems are minimized because input signals are less likely to be fed back to the input through the tube's internal capacitance.
2. Tetrodes can be used at higher frequencies than triodes because a tetrode's interelectrode capacitance is negligible over a greater range.

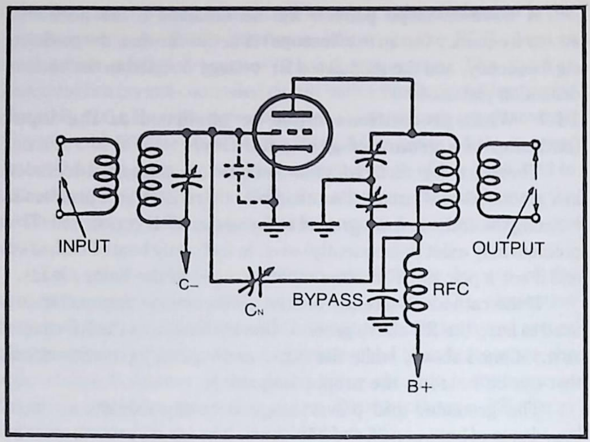


Fig. 14-5. Class C amplifier.

14-10 What is the principal advantage of a tetrode as compared with a triode when used in a radio receiver?

Elimination of the need for neutralization is the most important characteristic of the tetrode in receiver circuits. Triodes tend to oscillate because of the regenerative feedback that occurs when the output signal is coupled back to the grid in phase with the input signal. Such coupling causes squeals and whistles that disrupt the desired signal.

14-11 Draw a simple system of neutralizing the grid-plate capacitance of a single electron tube employed as an rf amplifier.

The class C amplifier pictured in Fig. 14-5 has a neutralizing capacitor (C_N) connected from the bottom end of the tank coil to the grid. The capacitor is adjustable so that the amount of feedback can be varied in accordance with the individual requirements of various tubes. The capacitor shown in broken lines represents the interelectrode capacitance of the tube. The feedback capacitance of C_N is adjusted to the point where the interelectrode capacitance is precisely canceled. The neutralizing capacitor could not be connected to the other side of the tank coil, because cancellation of the interelectrode capacitance depends on feeding back a signal that is 180° out of

phase with the signal existing on the grid. There would be no such phase reversal if the capacitor were connected at any other point than the one shown.

14-12 Why must some rf amplifiers be neutralized?

Neutralization is employed in some rf amplifiers to avoid oscillation. Interelectrode capacitances, such as that typically encountered in triode vacuum tubes, result in positive feedback of signals. Neutralization offsets the capacitance of the feedback paths.

14-13 What is the two-tone test in an rf amplifier?

The two-tone test is a method of checking the operation of an amplifier, and is used in conjunction with an oscilloscope. Two tones on a pair of rf signals of equal amplitude about 1000 cycles apart are sent through the amplifier. If the resulting waveform appears as two sine waves folded one on the other, the amplifier is operating properly.

14-14 What is the method commonly used to test the linearity of an amplifier?

The common method to check the linearity of a linear amplifier is to connect an oscilloscope to its output and apply a signal to the amplifier's input that varies from zero to the maximum allowable input. The output waveform shape as it appears on the oscilloscope should match the input waveform shape at any given input level.

14-15 How are distortion tests made in linear amplifiers?

The test setup for amplifier distortion is the same as that used for linearity checks; that is, a scope is connected to the output and a signal (or signals) applied to the input.

14-16 How is the oscilloscope used?

The oscilloscope is designed for use as a test instrument. It is capable of visually displaying the results of any number of tests on an electronically excited screen.

Among the oscilloscope's many practical applications are the following: alignment of radio receiving and transmitting equipment, hum measurement, frequency comparison, waveform observation, percentage of modulation, and many other similar applications. A block diagram of a simple oscilloscope is shown in Fig. 14-6.

The voltage waveform to be examined may be applied directly to the vertical deflection plates of the CRT. In most cases, however, the voltage to be presented is either too small or too large in amplitude to be examined. It must be either amplified or attenuated.

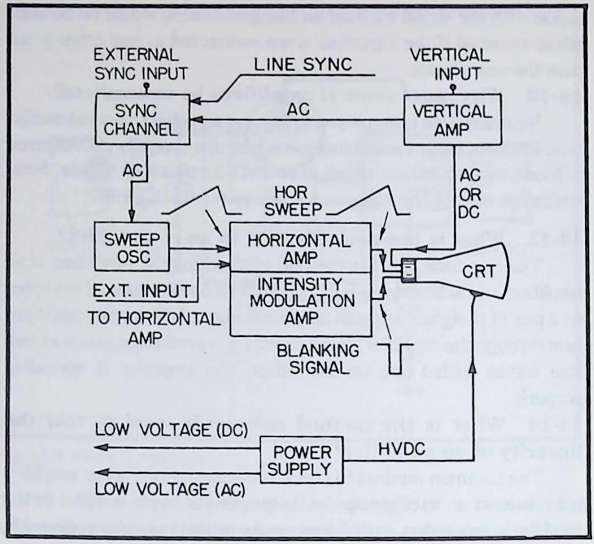


Fig. 14-6. Block diagram of a simple oscilloscope.

The amplification or attenuation of the input to the vertical deflection plates is accomplished by the vertical deflection amplifier circuit.

If a voltage is applied to the vertical deflection plates without a voltage applied to the horizontal deflection plates, only a thin vertical line will appear at the face of the scope.

The purpose of the horizontal deflection amplifier is to establish the desired amplitude of sweep voltages applied to the horizontal deflection plates of the CRT. The sweep voltage will control the beam deflection across the face of the CRT. The input to the horizontal amplifier may be selected from the sweep oscillator in Fig. 14-6, or from some external source.

If the screen of the CRT is observed without a vertical signal applied, only a horizontal line would be present on the face of the CRT. The length of the horizontal line is dependent upon the amplitude of the sweep voltage applied to the horizontal deflection plates. The amplitude of the sweep voltage applied to the horizontal deflection plates is controlled by the horizontal gain control.

14-17 How is a marker generator used?

A marker generator is used in conjunction with a sweep generator. The sweep generator sweeps across the frequency spectrum from one limit to another, and the circuit output is monitored on an oscilloscope. A marker generator emits a small signal at preset frequencies, which can be observed on the scope. Sweep generators have marker generators built in that are capable of accurate calibration. The marker indicates the frequency at various points on the response (output) curve by superimposing a marker signal on the curve, as viewed on the scope. If a marker generator is not built into the sweep generator, a separate marker generator can be used in parallel with it.

14-18 How is a calibrated receiver calibrated?

A calibrated receiver means that a secondary frequency standard is built into the receiver. It is a low power fixed frequency crystal-controlled oscillator, usually 100 kHz, whose harmonics are used to calibrate the receiver operating frequencies. The secondary frequency standard itself can be calibrated with signals from WWV.

14-19 Explain the use of a reflectometer.

In amateur radio, an SWR bridge is often referred to as reflectometer. Strictly speaking, a reflectometer is a device used t measure the time required for a pulse to travel to a point and return. In amateur radio transmission lines, voltage going toward the antenna is called "forward" or "incident" voltage, while that returning is called "reflected." It is possible to use a bridge circuit that will separate these two components so that each can be measured. This circuit is frequently called a reflectometer.

14-20 What is crossmodulation in a receiver system?

Crossmodulation is the term used to define the condition encountered when an unwanted signal modulates a desired signal. The condition arises when an unwanted strong signal is amplified by the rf amplifiers, even though the receiver is tuned to another frequency.

14-21 Explain "sensitivity" and "selectivity" of a receiver. Why are these important quantities? In what typical units are they usually expressed?

Sensitivity. The sensitivity of a receiver is its signal-responding capability. The more sensitive a receiver is, the better that receiver will "hear" very weak signals. Since sensitivity is compromised when noise is received along with the signals, a re-

ceiver's sensitivity is usually accompanied by a figure that expresses the receiver's noise immunity. Sensitivity is normally expressed in microvolts, while noise immunity is expressed in decibels. A good communications-type AM receiver might have a sensitivity of 0.5 μV with a ratio of signal-plus-noise to noise of 10 dB.

Selectivity. A receiver's selectivity figure is an expression that describes its vulnerability to interference from signals other than those on the desired frequency. A nonselective receiver, such as one of the regenerative types, may have an extremely good sensitivity value, but this is of little help if the receiver is not capable of rejecting signals appearing on frequencies adjacent to the frequency of interest. By the same token, a receiver that is relatively insensitive could prove far more usable than a sensitive receiver if it has a markedly superior selectivity figure, particularly when used in an area where incoming signals are especially strong and closely spaced in frequency. Selectivity is often expressed in hertz or kilohertz; the numerical value itself usually refers to the bandpass of the receiver, from a signal's lower half-power point to its upper half-power point.

14-22 Explain desensitation in a receiver.

Desensitation occurs in a receiver when a strong unwanted signal is present at the antenna. It differs from crossmodulation in that neither the desired signal nor the unwanted signal can be heard. The presence of the strong signal reduces the sensitivity of the receiver to the desired signal. This condition is frequently observed at repeater locations where transmitter and receiver operate simultaneously in close proximity.

14-23 Why do vacuum tubes produce random noise?

The noise produced by high-gain audio amplifier stages is attributable to high-temperature electron "boiloff." As electrons free themseleves from the structure of the cathode, the friction within the cathode is a source of minute broad-spectrum thermal noise, which can be amplified and regenerated along with the audio signal itself. Another cause is shot effect, a random variation in the quantity and velocity of emitted electrons. These conditions are inherent in thermionic tubes. To overcome them, amplifiers employ negative feedback (which reduces the amplifier gain) and use a number of amplifier stages. This tends to keep the signal-to-noise ratio high enough so that random noises will not be objectionable.

14-24 Discuss the cause and prevention of interference to radio receivers installed in motor vehicles.

Even though most sources of interference are of a pulsing nature—which makes them equivalent to AM components—FM receivers are susceptible to these noises. Mobile interference stems from the making and breaking of electrical contacts in the ignition system; the high-frequency contacting of generator brushes and alternator "whine"; and the electrical transients generated in all types of small electrical motors, such as windshield wipers, electric fuel pumps, air conditioners, and car heaters. Many of these sources produce spark gap-type signals that radiate from the devices themselves; they also produce transients which may propagate through the wiring of the vehicle.

Eliminating these interference sources is a matter of shielding, using better and more effective grounds, and incorporating filter-type inductors in the lines that supply power to interference sources. At the receiver an improvement can often be noted after carefully installing bypass capacitors in strategic locations.

14-25 In which one of the following would a frequenc discriminator circuit be used?

A. **Single sideband transmitter**
B. **AM receiver**
C. **FM exciter**
D. **Double sideband transmitter**
E. **FM receiver.**

Answer: *E*.

14-34. Discuss the causes and possible cures of fast-flutter and [illegible] in [illegible]

[illegible]

14-35. In which one of the following would a frequency discriminator not be used? [illegible]

[illegible]

14-36. [illegible]

[illegible]

Chapter 15
Operating Procedures

Most of the pleasure to be derived from amateur radio comes from operating the station, although for the *home-brew* builder, a great deal of satisfaction is obtained when a hand-built transmitter or receiver operates for the first time. Whether the station is of a commercial variety purchased at the local ham store, or meticulously constructed at home, various operating procedures must be followed. Some of these are out of courtesy to neighbors and fellow amateurs while other procedures carry the full weight of the law.

In this chapter we will look at the considerations each of us must have in station operation. The last question in the chapter is a sample question prepared by the FCC.

15-1 Whose responsibility is it to eliminate or reduce interference in broadcast radio and television receivers affected by amateur radio equipment?

Your first thought might be that if operation of the amateur radio equipment causes television interference (TVI) and broadcast interference (BCI), then obviously the responsibility rests with the amateur radio operator. Actually, there are three categories of interference problems, and usually the amateur station is at fault. But a poorly designed receiver could be to blame, or some unpredictable happening brought about by Mother Nature could cause an interaction between the amateur equipment and the receiver. No

matter the cause, it is always good public relations for the amateur to do all that he can to reduce interference to a minimum.

15-2 How are BCI and TVI reduced or eliminated?

Interference can take many forms. Automotive devices such as generators, ignitions, electrical accessories, etc. cause problems in vehicles; and machines, appliances, power lines, and the like are trouble sources at fixed locations. Interference can also be caused by harmonic and spurious radiation from other transmitters, oscillator signals from nearby receiving equipment, intermodulation from two signals mixing at some nonlinear element, and from other stations operating either on the same channel or adjacent frequencies.

There are two basic approaches to minimizing interference: The first is to take measures at the source of the interference, and the second is to exercise preventive measures at the receiver. When interference is reduced by doing something at the source of the radiation, that is sometimes called *active elimination* or interference. When steps are taken at the receiver, it is called *passive elimination* of interference.

Active Approaches. When rf interference is attributable to man-made sources, several standard measures are often adopted to reduce the problem. Bypass capacitors across suspect circuits; rf chokes in series with DC power lines; and additional, heavier ground cables all help to reduce radiation from vehicular sources. Shielding is also a powerful weapon, but more often than not it becomes impractical either because of the size of the offending device or the basic construction requirements of the device.

When the source of the interference is another transmitter, it is best to determine the exact nature of the problem. Parasitic chokes can be used to suppress parasitic radiation, as can rerouted leads and the addition of new ground points in the transmitter (when the offending transmitter's chassis is doing the radiating). If the problem is attributable to a self-oscillating stage, the problem can often be cured by neutralization.

An extremely effective deterrent to harmonic radiation is the low-pass filter, which should be installed in the transmitter's transmission line. A low-pass filter will tend to suppress radiation of all signals beyond those for which the transmitter was designed.

Passive Approaches. If the interference is caused by other stations operating on adjacent frequencies or even the same fre-

quency, the use of a directional antenna might prove extremely beneficial. Not only does a directional antenna reduce the receiver's sensitivity to stations other than those in the path of its beam, it adds considerable gain to signals lying within the beam.

In vehicular receivers, ignition noise and other pulse-type problems can be minimized by effective grounding of the receiver and, possibly, shielding the lines bringing power to the unit.

The most widespread approach to BCI and TVI at the receiver is to install a filter that will eliminate the unwanted signals. This, along with readjusting the receiver's antenna, may null out the interference.

15-3 What is meant by "parasitic oscillations?" How may they be detected and prevented?

Parasitic oscillations are signals generated within an rf amplifier other than by design. Not all combinations of input and output circuits in a transmitter can be used together successfully, since some of them tend to permit the amplifier stage to oscillate at frequencies that are relatively unrelated to the frequency to which it is tuned. These oscillations are undesirable because they cause the transmission of spurious signals, thus impairing the efficiency of the rf amplifier and causing needless interference to radio reception.

The most noticeable features of parasitic oscillation in an amplifier are erratic tuning and the radiation of spurious signals. When an rf amplifier is operating properly, the DC plate current dips sharply as the tank circuit is tuned through resonance. This plate current dip also corresponds to maximum power output and (usually) maximum grid current into the final amplifier. If a tetrode is operating normally, the plate current change may not be too great, but the screen current dip will still be significant. With parasitic oscillation, the plate current may not dip at all, the minimum may not correspond to maximum power output, several dips may appear in the tuning range, or grid current to the final amplifier will not coincide with the dip in the plate current reading of the final amplifier.

Since the symptoms presented by a stage that is not properly neutralized are somewhat similar, it is difficult to tell the effects of the two conditions apart unless neutralization is checked first.

All parasitics are attributable to the development of resonant circuits in connection with the tube elements in such a way as to permit enough feedback as to sustain oscillation. They may occur at

either high or low frequencies. Parasitic oscillations occurring at much lower than the operating frequency usually are caused by the resonant condition of an rf choke in the circuit, since the rf chokes are the only inductors with sufficient inductance to resonate with various circuit capacitances at low frequencies. High-frequency parasitics can be traced to a much wider variety of causes. Among these are spurious high-frequency resonant conditions in tank circuit inductances, resonant circuits built up in lead inductances, and stray capacitances and resonant conditions built up in bypass and blocking capacitors. Moreover, the parasitic circuit need not involve the final amplifier alone. The driver stage is frequently an important part of the parasitic feedback circuit that permits oscillation.

A recurrent type of high-frequency oscillation is caused by a form of tuned-plate, tuned-grid oscillator in a simple single-ended amplifier like that of Fig. 15-1. The parasitic path is shown in heavy lines. At relatively high frequencies the tank circuit inductance acts like an rf choke, and the capacitors and their leads form the equivalent of parallel resonant circuits. The shielding effect of the screen grid in a tetrode is not sufficient at extremely high frequencies. Therefore, energy can feed back to the grid circuit from the plate at high frequencies if both of the parasitic resonant circuits are almost the same in frequency. The difficulty can be cured by inserting a parallel inductance and resistance in the grid or plate lead. This detunes one of the parasitic circuits sufficiently to prevent oscillation. (Usually, the process is no more complex than wrapping a few turns of 16-gauge solid wire around a carbon resistor so that both the resistance and the inductance are paralleled.)

Another method is to insert a small resistance in series with circuit leads to introduce sufficient loss to stop oscillation. A third alternative is to incorporate a tuned parallel resonant trap that actually inserts a very high impedance in the parasitic frequency path. In addition to the trap, it is common to find small high-frequency capacitors connected from plate and control grid to cathode. These capacitors effectively short the parasitics to ground.

Certain circuit combinations have been found to be particularly troublesome. For example, rf chokes rarely are used in both the grid and the plate circuits of a triode, since they cause a low-frequency tuned-plate, tuned-grid oscillation (Fig. 15-1B). Hence, shunt-fed circuits are avoided wherever possible. In high-gain screen grid

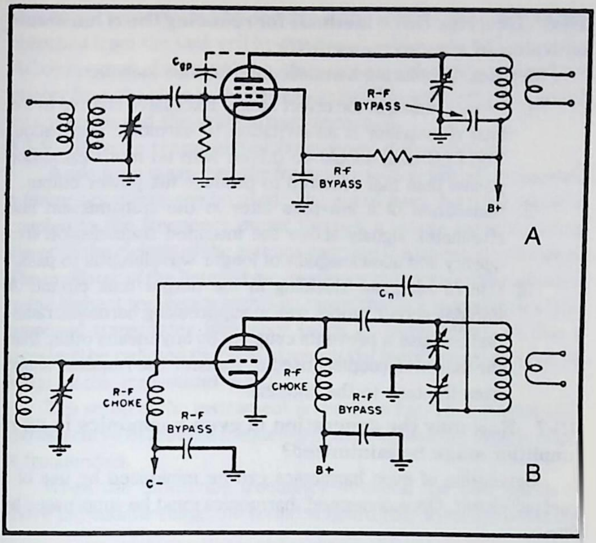


Fig. 15-1. TPTG oscillator in a single-ended amplifier.

amplifiers, the choice of the screen bypass capacitor becomes very important. The substitution of a different type when servicing a unit often leads to serious instability. Similarly, the choice of cathode and filament bypass capacitors is also a critical matter. When replacing any of these components in a transmitter, use the exact duplicate of the discarded component and pay careful attention to lead dress and parts placement.

15-4 What is meant by a "harmonic"?

A harmonic is a multiple of any referenced frequency. However, the first harmonic is regarded as the fundamental frequency being referenced; so the second harmonic is a signal at twice the frequency of the fundamental, the third harmonic is a signal three times the fundamental, and so forth.

15-5 What is the seventh harmonic of 360 kHz?

The seventh harmonic of any frequency is a frequency that is seven times the referenced, or fundamental, frequency. Thus 2520 kHz (2.52 MHz) is the seventh harmonic of 360 kHz.

15-6 Describe three methods for reducing the rf harmonic emission of a radio transmitter.

Methods of reducing harmonic interference include:

1. Proper tuning of the driver stage. Excessive rf drive to the final rf amplifier is an invitation to harmonic generation. The final tank should be driven with no more excitation power than that required to produce full power output.
2. Installation of a low-pass filter in the transmission line attenuates signals above the intended transmission frequency and allows signals of longer wavelengths to pass.
3. Use of adequate shielding in the output tank circuit. A Faraday screen works well in suppressing harmonic radiation because it prevents coupling by any means other than the inductive coupling used to transfer the required signal from the tank to the antenna.

15-7 How may the generation of even harmonics in an rf amplifier stage be minimized?

Generation of even harmonics can be minimized by use of a pushpull circuit. Once generated, harmonics must be suppressed by filters.

5-8 What is a grid-dip meter and how it it used?

The grid dipper is now obsolete, having been replaced by transistor and FET dippers. Still, the question does appear in the exams, and it behooves the applicant to know the circuit and its applications.

With dip meters, it is possible to determine the resonant frequency of an antenna system, to detect harmonics, and to check relative field strengths (for example, in rotating an antenna for maximum signal strength). The meter may also be used as an absorption frequency meter when the oscillator of the dipper is not energized.

Basically, the grid-dip meter is a calibrated oscillator which meters the grid current in the oscillator circuit. With the oscillator functioning, energy is coupled from the tuned circuit to the circuit under test. The circuit under test is supplied a small amount of energy via a tank coil of the meter. Except for the field of the tank coil, the circuit under test is deenergized. Capacitors are adjusted to the point where the oscillator tank frequency is equal to the resonant frequency of the circuit under test. At resonance the grid current

decreases, as indicated by the dip in the grid meter. The energy absorbed from the tank coil by the circuit under test decreases the AC component of plate voltage, thus causing a decrease in feedback energy from the plate to the oscillator grid. The grid voltage is driven less positive and the grid current decreases.

15-9 How is transmitted frequency determined?

Aside from measuring the frequency with a calibrated receiver, a frequency meter can be used. The signal from the transmitter is coupled to the frequency meter through a simple antenna pickup placed in the vicinity of the antenna carrying the transmitter's signal. The oscillator of the heterodyne frequency meter should be adjusted to the highest frequency within its range that is a submultiple of the supposed transmitter frequency (such as 36.69 MHz), so that a signal will be radiated that is as strong at the fourth harmonic (146.76 MHz) as the transmitter signal.

The setup of the instrument is shown in Fig. 15-2. Figure 15-3 shows a curve of the beat frequency plotted against the audible range of frequencies.

When the difference frequency between the two signals is above the audible range, no sound is heard (the shaded area on the

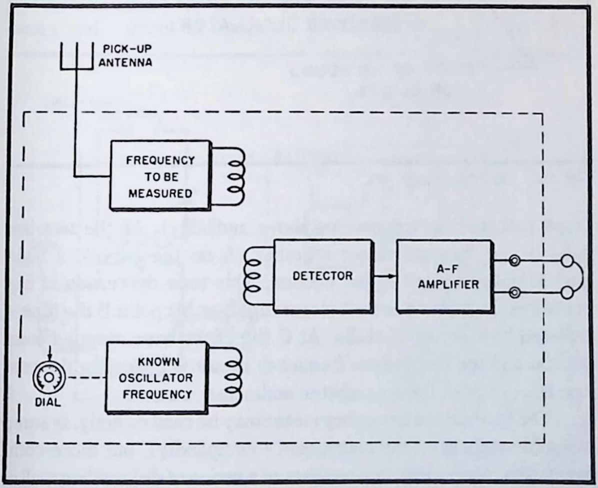


Fig. 15-2. Functional block diagram of a frequency meter.

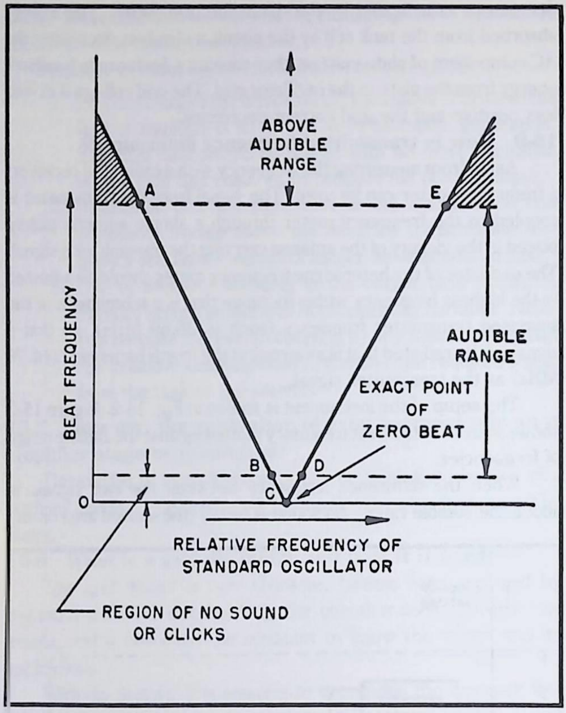


Fig. 15-3. Beat frequency plot.

graph indicates the frequencies above audibility). As the two frequencies are brought closer together (A on the curve), a high-pitched note is heard in the phones. This tone decreases in frequency as the frequencies get closer together. At point B the tone is replaced by a series of clicks. At C the clicks have stopped completely, and the heterodyne frequency meter is indicating the precise frequency of the transmitter under test.

The heterodyne frequency meter may be read directly, in some cases (depending on the instrument's complexity); but more commonly, the meter indication consists of a series of dial readings, all of which have to be combined into a single multidigit number and

compared against an entry in a special calibration book before the frequency represented by the number can be determined.

If a receiver is available, the process of frequency determination is simplified. Use the rf output capability of the heterodyne frequency meter to generate a signal that can be picked up by the receiver. The transmitter is then keyed. When the frequency meter's output signal is about the same strength as the signal radiating from the transmitter, the frequency meter is simply adjusted until a beat note is heard in the receiver. In this case the clicks are replaced by the varying tone. As the tone drops in pitch, the two signals are closing in on each other. At zero beat—the point where no tone is heard unless the frequency meter's dial is touched—the two signals are exactly on the same frequency.

Digital frequency meters display the frequency measured in direct readout.

15-10 What is a wavemeter, and how does it operate?

Figure 15-4 shows an absorption wavemeter using a galvanometer to register changes in circuit current. When the wavemeter circuit is tuned to the same frequency as the unknown frequency of the device under test, a maximum circulatory current flows in the wavemeter circuit. Since this circulatory current occurs at resonance and current is maximum in this condition, voltage drops

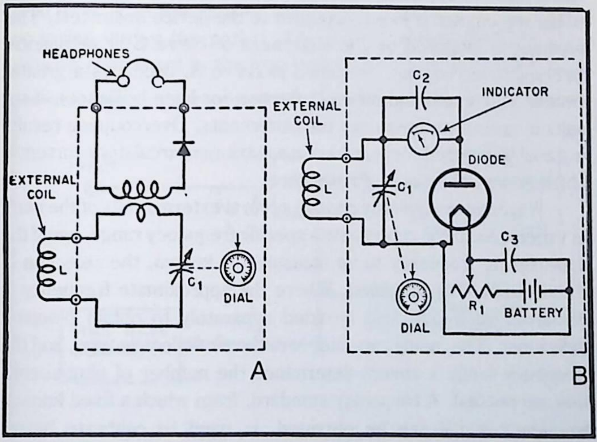


Fig. 15-4. Absorption wavemeter circuits.

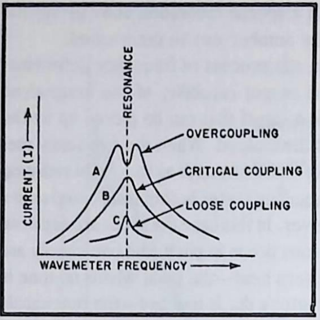


Fig. 15-5. Circulatory current plot.

appear across L, C1, and C2; the voltage drop across C2 causes the galvanometer to deflect. (The galvanometer may be replaced with an ordinary small lamp, which can be made to glow under maximum-current conditions.) As C1 is tuned to either side of resonance, the circulatory current becomes less and the meter indication diminished (lamp grows dimmer).

In Fig. 15-5 the circulatory current is plotted against the wavemeter frequency for various degrees of coupling between the resonant circuit of the device under test and the tank coil of the wavemeter. For accurate frequency measurements the external coil of the wavemeter is loosely coupled to the device under test. This accuracy is indicated by the sharpness of curve C at resonance. Although overcoupling, as shown in curve A, produces a greater circulatory current and meter deflection (or lamp brilliance), it results in inaccurate frequency measurements. Overcoupling results in a double-humped curve, wherein a maximum circulatory current is obtained on either side of resonance.

Wavemeters typically contain several external coils of the plug-in variety. Each coil represents a specific frequency range, and if the approximate frequency to be measured is known, the selection of the proper coil is simplified. Where the approximate frequency is unknown, each coil must be tried separately to obtain resonant indications. The tuning capacitor is of the air dielectric type, and the frequency range it covers determines the number of plug-in coils that are needed. A frequency standard, from which a fixed known-frequency signal can be obtained, is used to calibrate better wavemeters.

15-11 Explain the operation of a digital secondary frequency standard.

The counter-type frequency meter is a high-speed electronic counter with an accurate, crystal-controlled time base. This combination provides a frequency meter that automatically counts and displays the number of events or cycles occurring in a precise time interval. A simplified block diagram of a representative secondary standard is shown in Fig. 15-6.

In addition to making direct frequency measurements, the counter can measure periods (DC to 100 kHz, for most basic instruments, and considerably higher with the addition of a prescaler), frequency ratios, and total events. A self-check feature enables an operator to verify instrument operation for most types of measurements. The internal oscillator is stable within a few parts in 10ᑦ million, generally. Thus, these counters make good secondary fr quency standards.

For frequency measurements the signal is fed through a sig gate to a series of digital counters. A precision time interval obtaine from the time-base section opens and closes the signal gate for an extremely accurate period of time (for example, one second). The counter counts the number of cycles entering through the gate during the one-second interval and displays the total. The answer is read directly as the number of kilohertz (or hertz, or megahertz) occurring during the period. The period of time the signal gate remains open is set by the frequency unit switch. For each position

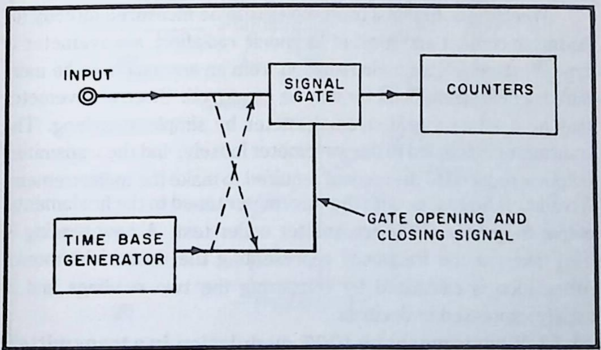


Fig. 15-6. Simplified block diagram of a secondary standard.

of this switch, the illuminated decimal point is automatically positioned so that the answer is always read directly. The answer is automatically displayed for a period of time determined by gate time or the setting of the display time control on the front panel, whichever is greater.

To measure a period or time interval, the application of the two signals reverses, as shown by the dotted lines in Fig. 15-6. The period or time interval to be measured is connected to "open" and "close" the signal gate while one of the standard frequencies from the time base is passed through the signal gate to the counters. When measuring a period, one cycle of the incoming signal opens the gate, and the next cycle closes it. The number of cycles of the standard frequency from the time base that occurred during the period are then indicated on the counters. The standard frequencies obtained from the time base are selected so that the answer to the measured period will always be displayed directly in units of time (seconds, milliseconds, nanoseconds, or microseconds).

Provision is also made in the circuit to permit measurement of the average of 10 periods of the unknown frequency. Higher accuracy can thus be obtained than with single-period measurements.

The accuracy of frequency measurements is determined by an internal oscillator and by a possible error of plus or minus one digit—the least-significant of the entire readout. (The least significant digit is at the extreme right of a displayed number.)

15-2 Describe a usual method (and equipment used) for measuring the harmonic attenuation of a transmitter.

When the output of a transmitter is to be measured directly for harmonic content and level of harmonic radiation, a wavemeter is typically used. If harmonic radiation from an antenna is to be measured, a field strength meter may be employed. Often a wavemeter may be used as a field strength meter by simple switching. The transmitter is coupled to the wavemeter loosely, and the transmitter output is reduced to the amount required to make the measurement. A reading is first taken with the wavemeter tuned to the fundamental output frequency of the transmitter under test. A new reading is then taken at the frequency representing the desired harmonic. Attenuation is calculated by comparing the two readings and is usually expressed in decibels.

15-13 What is meant by 100% modulation in a transmitter?

The depth or degree of modulation is defined in terms of the maximum permissible amount of modulation. Thus, a fully modulated wave is said to be 100% modulated. The modulation envelope in Fig. 15-7 shows the conditions for 100% sine wave modulation. For this degree of modulation the peak audio voltage must be equal to the DC supply voltage to the final power amplifier. Under this condition the rf output voltage will reach zero on the negative peak of the modulating signal and will rise to two times the amplitude of the unmodulated carrier on the positive peak of the modulating signal.

When analyzed, the modulation envelope in part A of Fig. 15-7 is found to consist of a carrier and two sideband frequencies as shown in part B of this Figure. Since for 100% modulation the peak audio modulating voltage is approximatley equal to the peak rf voltage, the combined sideband voltage is equal to the carrier voltage. Because the sideband voltage is divided between two sideband frequencies, at 100% modulation each side frequency has a amplitude equal to one-half the amplitude of the carrier.

15-14 Explain the consequences of overmodulation in a transmitter.

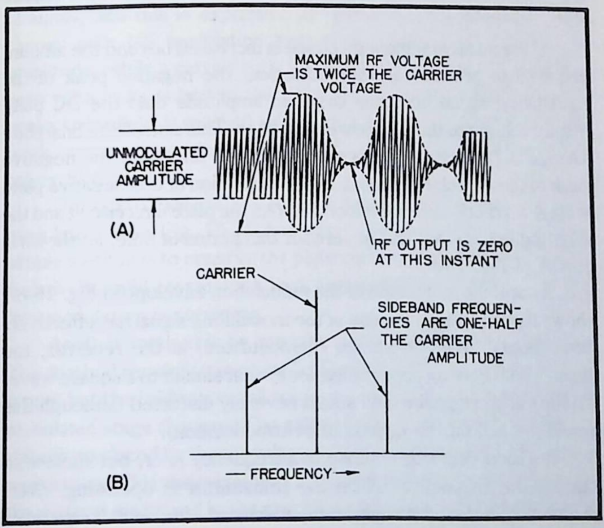


Fig. 15-7. Modulation envelope and sideband frequencies.

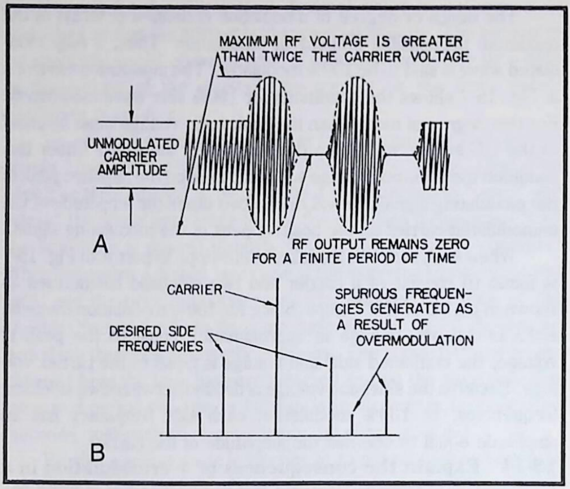


Fig. 15-8. The effects of overmodulation on the envelope and sideband frequencies.

If the audio modulating voltage is increased beyond the amount quired to produce 100% modulation, the negative peak of the odulating signal becomes larger in amplitude than the DC plate upply voltage to the final power amplifier. This causes the final plate voltage to be negative for a short period of time near the negative peak of the modulating signal. For the duration of this negative plate voltage no rf energy is developed across the plate tank circuit and the rf output voltage remains at zero for this period of time, as shown in part A of Fig. 15-8.

A careful examination of the modulation envelope in Fig. 15-8A shows that the negative peak of the modulating signal has effectively been clipped. When detected (demodulated) in the receiver, the signal would have an appearance somewhat similar to a square wave. To the ear the signal would sound severely distorted (although this would depend on the degree of overmodulation).

If a radio receiver is tuned to a frequency near, but somewhat outside the channel on which the transmitter is operating, overmodulation is found to generate unwanted sideband frequencies which appear for a considerable distance above and below the de-

sired channel. This effect is sometimes called "splatter." These unwanted or "spurious" frequencies shown in part B of Fig. 15-8, cause interference to other stations operating on adjacent channels. It should be clearly understood that overmodulation and its attendant distortion and interference are to be avoided.

In addition to the above problems, overmodulation also causes abnormally large voltages and currents to exist at various points within the transmitter. Where sufficient overload protection by circuit breakers and fuses is not provided, these excessive voltages can cause arcing between transformer windings and between the plates of capacitors, permanently destroying the dielectric material. Excessive currents can cause overheating of tubes and other components.

15-15 How is modulation measured?

Except for CW communications, the "intelligence" in an rf signal is usually in the modulation. In an amplitude modulated (AM) signal, the amplitude of the carrier is increased and decreased by "impressing" the modulation onto the carrier frequency. Measurement consists of determining the degree of modulation applied to the rf signal, and this is expressed in "percentage of modulation." A carrier with 0% modulation has no increase or decrease in its amplitude, while a carrier with 100% modulation will vary between zero volts at its output to twice the carrier voltage. Each of these peaks and valleys is reached only for just an instant. In amateur radio work, we are interested in about 80% modulation, to allow a 20% safety factor.

The best device is a scope for measuring the percentage of modulation (see Fig. 15-7), but other devices may be used. One simple method is to observe the plate current meter. If it is unstable (relatively rapid movements back and forth), the chances are that overmodulation is occurring.

Another method is by use of a high-resistance AC voltmeter. This method requires a onetime "calibration" of the voltmeter with a scope, but the calibration will not be correct if the DC voltage to the modulated stage changes. The voltmeter is used to measure the AC voltage produced by the modulator, and is calibrated in percentage of modulation. This measurement is considerably more accurate than the method discussed in the previous paragraph—the plate-current indication method.

Simple circuits have been designed that use neon tubes that glow when modulation reaches certain levels, such as 50%, 80%, and 100%. These circuits employ a voltage divider network and switching diodes.

15-16 What is the purpose of a "dummy" antenna?

A dummy antenna (dummy load) is a resistive (noninductive) device such as a carbon resistor, capable of dissipating the transmitter's output power without overheating. The dummy antenna offers a resistive load to the transmitter that is the same value as the antenna's impedance. The purpose is to allow the transmitter to be tuned and peaked on the frequency of operation without radiating a signal (which might cause interference to other stations). After the dummy load has been used to tune the transmitter's tank and rf stages, it is removed and the antenna is connected in its place. When the impedance of the load is the same value as the characteristic impedance of the antenna, no retuning will be required.

15-17 What are the FCC rules regarding station identification?

An amateur station shall be identified by the transmission of its call sign at the beginning and end of each single transmission or exchange of transmissions and at intervals not to exceed 10 minutes during any single transmission or exchange of transmissions of more than 10 minutes duration. Additionally, at the end of an exchange of telegraphy (other than teleprinter) or telephony transmissions between amateur stations, the call sign (or the generally accepted network identifier) shall be given for the station, or for at least one of the group of stations, with which communication was established.

When an amateur station is operated as a portable or mobile station, the operator shall give the following additional identification at the end of each single transmission or exchange of transmissions:

1. When identifying by telegraphy, immediately after the call sign, transmit the fraction-bar $\overline{\text{DN}}$ followed by the number of the call sign area in which the station is being operated.
2. When identifying by telephony, immediately after the call sign, transmit the word "portable" or "mobile," as appropriate, followed by the number of the call sign area in which the station is being operated.

When an amateur station is operated outside of the 10 call sign areas and outside of the jurisdiction of a foreign government, the

operator shall give the following additional identification at the end of each single transmission or exchange of transmissions:

1. When identifying by telegraphy, immediately after the call sign, transmit the fraction-bar $\overline{\text{DN}}$ followed by the designator R1, R2, or R3, to show the region (as defined by the International Radio Regulations, Geneva, 1959) in which the station is being operated.
2. When identifying by telephony, immediately after the call sign, transmit the word "mobile" followed by the designator Region 1, Region 2, or Region 3, to show the region (as defined by the International Radio Regulations, Geneva, 1959) in which the station is being operated.

Under conditions when the control operator is other than the station licensee, the station identification shall be the assigned call sign for that station. However, when a station is operated within the privileges of the operator's class of license but which exceeds thos of the station licensee, station identification shall be made by follo ing that station call sign with the operator's primary station call s (i.e. WN4XYZ/W4XX).

A repeater station shall be identified by radio telephony or radio telegraphy when in service at intervals not to exceed 5 minutes at a level of modulation sufficient to be intelligible through the repeated transmission.

A control station must be identified by its assigned station call sign unless its emissions contain the call sign identification of the remotely controlled station.

An auxiliary link station must be identified by its assigned station call sign unless its emissions contain the call sign of its associated station.

The identification required by this section shall be given on each frequency being utilized for transmission and shall be transmitted either by telegraphy using the International Morse Code, or by telephony, using the English language. If by an automatic device only used for identification by telegraphy, the code speed shall not exceed 20 words per minute. The use of a national or internationally recognized standard phonetic alphabet as an aid for correct telephone identification is encouraged.

15-18 What are the FCC rules and regulations regarding emergency operations?

Section 97.101 of the FCC rules and regulations states:

In the event of an emergency disrupting normally available communication facilities in any widespread area or areas, the Commission, in its discretion, may declare that a general state of communications emergency exists, designate the area or areas concerned, and specify the amateur frequency bands, or segments of such bands, for use only by amateurs participating in emergency communication within or with such affected area or areas. Amateurs desiring to request the declaration of such a state of emergency should communicate with the Commission's Engineer in charge of the area concerned. Whenever such declaration has been made, operation of and with amateur stations in the area concerned shall be only in accordance with the requirements set forth in this section, but such requirements shall in nowise affect other normal amateur communication in the affected area when conducted on frequencies not designated for emergency operation.

(a) All transmissions within all designated amateur communications bands other than communications relating directly to relief work, emergency service, or the establishment and maintenance of efficient amateur radio networks for the handling of such communications shall be suspended. Incidental calling, answering, testing or working (including casual conversations, remarks or messages) not pertinent to constructuve handling of the emergency situation shall be prohibited within these bands.

(b) The Commission may designate certain amateur stations to assist in the promulgation of information relating to the declaration of a general state of communications emergency, to monitor the designated amateur emergency communications bands, and to warn noncomplying stations observed to be operating in those bands. Such station, when so designated, may transmit for that purpose on any frequency or frequencies authorized to be used by that station, provided such transmissions do not interfere with essential emergency communications in progress; however, such transmissions shall preferably be made on authorized frequencies immediately adjacent to those segments of the amateur bands being cleared for the emergency. Individual transmissions for the purpose of advising other stations of the existence of the communications emergency shall refer to this section by number (97.107) and shall specify, briefly and concisely, the date of the Commission's declaration, the area and nature of the emergency, and the amateur fre-

quency bands or segments of such bands which constitute the amateur emergency communications bands at the time. The designated stations shall not enter into discussions with other stations beyond furnishing essential facts relative to the emergency, and the operators of such designated stations shall report fully to the Commission the identity of any stations failing to comply, after notice, with any of the pertinent provisions of this section.

(c) The special conditions imposed under the provisions of this section shall cease to apply only after the Commission, or its authorized representative, shall have declared such general state of communications emergency to be terminated: however, nothing in this paragraph shall be deemed to prevent the Commission from modifying the terms of its declaration from time to time as may be necessary during the period of a communications emergency, or from removing those conditions with respect to any amateur frequency band or segment of such band which no longer appears essential to the conduct of the emergency communications.

The frequency 4383.8 kHz may be used by any stations authorized under this part of communicate with any other station in the State of Alaska for emergency communications. No airborne operations will be permitted on this frequency. Additionally, all stations operating on this frequency must be located in or within 50 nautical miles of the State of Alaska.

15-19 When an amateur station is operated as a portable or mobile station,

A. The word "portable" or "mobile" and the call area designator must precede the operator's call sign.
B. Transmission of the station call sign at the end of each transmission not exceeding 10 minutes duration, is not required.
C. Advanced written notice for operation at single location for a period of 30 days is not required.
D. Such mobile operation is not permissible aboard ships or aircraft.
E. A notice of operation away from an authorized location is not required where the portable or mobile operation consists entirely of transmissions directed only to a remote model craft or vehicle.

Answer: *E*

[illegible]

[illegible]

12.13 [illegible]

A. [illegible]

B. [illegible]

C. [illegible]

D. [illegible]

Chapter 16

FCC Rules and Regulations

The rules and regulations developed by the FCC are found in Part 97 of the official FCC Rules and Regulations. This part, covering amateur radio service, is available separately from the Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402 (Stock No. 004-000-00338-1) for about $1.50. The rules change relatively often, so it is wise to obtain your own personal current copy before taking the FCC exam. It is also recommended that all active amateur operators keep a current edition on hand.

The last question in the chapter is one prepared by the FCC as a sample.

16-1 Define the term amateur radio communication.

Amateur radio communication is the noncommercial radio communication by or among amateur radio stations solely with a personal aim and without pecuniary or business interest.

16-2 What is third-party traffic?

Third-party traffic is amateur radio communication by or under the supervision of the control operator at an amateur radio station to another amateur radio station on behalf of anyone other than the control operator.

16-3 Define the term control point.

Control point is the operating position of an amateur radio station where the control operator function is performed.

16-4 What is meant by remote control?

Remote control is a form of manual control, with a control operator on duty and monitoring the operation at a control point located other than at the station transmitter, such that the associated operating adjustments are accessible through a control link.

16-5 What is a control station?

A control station is a station licensed to conduct remote control of another amateur radio station.

16-6 Define emergency communications.

Emergency communication is any amateur radio communication directly relating to the immediate safety of life of individuals or the immediate protection of property.

16-7 What is the difference between fixed, portable, and mobile operation?

Fixed operation is radio communication conducted from the specific geographical land location shown on the station license. *Portable* operation is radio communication conducted from a specific geographical location other than that shown on the station license. *Mobile* operation is radio communication conducted while in motion or during halts at unspecified locations.

16-8 What frequencies may be used by the Technician class licensee? What emissions? What power?

The Technician class is authorized all amateur privileges on the frequencies 50.1-54.0 MHz and 145-148 MHz and in the amateur frequency bands above 220 MHz. On these frequencies, the Technician class may use any type of emission and transmitter power that is available to other amateur class licensees. A Technician class license also carries the full privileges of the Novice class license.

16-9 What are the limitations on operating frequency, emissions, and transmitter power to the General class licensees?

The General class licensees are authorized all amateur privileges of emission, power, and frequencies, except those frequencies reserved for the Advanced class and the Amateur Extra class. Those reserved frequencies are:

Amateur Extra Only

3500-3525 Khz
3775-3800 kHz
7000-7025 kHz

14,000-14,025 kHz
21,000-21,025 kHz
21,250-21,270 kHz

Amateur Extra and Advanced

3800-3890 kHz
7150-7225 kHz
14,200-14,275 kHz
21,270-21,350 kHz
50.0-50.1 MHz

16-10 What are the FCC rules regarding purity and stability of emissions?

Spurious radiation from an amateur station being operated with a carrier frequency below 144 megahertz shall be reduced or eliminated in accordance with good engineering practice. This spurious radiation shall not be of sufficient intensity to cause interference in receiving equipment of good engineering design including adequate selectivity characteristics, which is tuned to a frequency or frequencies outside the frequency band of emission normally required for the type of emission being employed by the amateur station.

In the case of A3 emission (amplitude modulated voice), the amateur transmitter shall not be modulated to the extent that interfering spurious radiation occurs, and in no case shall the emitted carrier wave be amplitude-modulated in excess of 100 percent. Means shall be employed to insure that the transmitter is not modulated in excess of its modulation capability for proper technical operation. For the purposes of this question a spurious radiation is any radiation from a transmitter which is outside the frequency band of emission normal for the type of transmission employed, including any component whose frequency is an integral multiple or submultiple of the carrier frequency (harmonics and subharmonics) spurious modulation products, key clicks, and other transient effects, and parasitic oscillations.

When using amplitude modulation on frequencies below 144 MHz, simultaneous frequency modulation is not permitted and when using frequency modulation on frequencies below 144 MHz simultaneous amplitude modulation is not permitted.

The frequency of the emitted carrier wave shall be as constant as the state of the art permits.

16-11 What frequencies are available for repeater station operation?

The following transmitting frequency bands are available for repeater stations, including both input (receiving) and output (transmitting):

Frequency Band (MHz)
29.5-29.7
52.0-54.0
146.0-148.0
222.0-225.0
442.0-450.0

and any amateur frequency about 1215 MHz.

16-12 What is the maximum effective radiated power of a repeater station?

The maximum effective radiated power (ERP) of a repeater station depends upon the frequency of transmission of the repeater station and the antenna height above the average surrounding terrain.

In the 52-54 MHz range, the maximum ERP cannot exceed 25W if the antenna height is 500 ft. or more, 50W between 100 and 499 ft., and 100W up to 99 ft.

In the 146-148 MHz range, the ERP cannot exceed 100W if the antenna height is 1000 ft. or more, 200W between 500 and 999 ft., 400W between 50 and 499 ft., and 800W up to 49 ft.

In the 442-450 MHz range, the ERP cannot exceed 400W if the antenna height exceeds 1000 ft., and 800W between 100 and 999 ft. If the height of the antenna is less than 99 ft., ERP is not considered. In this category and in the amateur frequencies above 1215 MHz the transmitter power restrictions are controlled by the maximum permissible power input to the plate circuit of the final amplifier stage.

16-13 What frequency bands may a control station use for control link emissions (to control operation of a repeater station)?

Amateur frequency bands above 220 MHz, excepting 435 to 438 MHz, may be used for emissions by a control station. Frequencies below 225 MHz used for control links must be monitored by the control operator immediately prior to, and during, periods of operation.

16-14 Are mobile or portable stations allowed to operate a remotely controlled station?

Where a remotely controlled station has been authorized to be operated from one or more remote control stations, those remote control stations may be operated either mobile or portable.

16-15 What are the requirements for the operation of a remotely controlled station?

An amateur radio station may be remotely controlled only from an authorized control point (control station), and only where there is compliance with the following:

1. A photocopy of the remotely controlled station license must be posted in a conspicuous place at the authorized control point(s), and at the remotely controlled transmitter location. A copy of the system network diagram must be retained at each control point. The transmitting antenna, transmission line, or mast, as appropriate, associated with the remotely controlled transmitter must bear a durable tag marked with the station call sign, the name of the station licensee and other information so that the control operator can readily be contacted by Commission personnel.
2. The control link equipment and the remotely controlled station must be accessible only to persons authorized by the licensee. Protection against both inadvertent and unauthorized deliberate emissions must be provided. In the event unauthorized emissions occur, the station operation must be suspended until such time as adequate protection is incorporated, or until there is reasonable assurance that unauthorized emissions will not recur.
3. Except for operation under automatic control, a control operator designated by the licensee must be present at an authorized control point while the station is being remotely controlled. Immediately prior to, and during the periods the remotely controlled station is in operation, the frequencies used for emission by the remotely controlled transmitter must be continuously monitored by the control operator. The control operator must terminate transmission upon any deviation from the rules.

4. Provisions must be incorporated to limit transmission to a period of no more than 3 minutes in the event of malfunction in the control link.
5. A repeater station may be operated by radio remote control only where the control link utilizes frequencies other than the repeater station receiving frequencies.

16-16 What precautions must be taken if a repeater station is operated under automatic control?

A repeater station licensed either for local control or for remote control may also be operated under automatic control where:

1. Devices and procedures have been implemented to assure that compliance with the rules can be accomplished without the duty control operator present at the control point at all times the station is in operation.
2. All radiocommunications transmitted by the station are monitored by the duty control operator in real-time, or are recorded so that they can be reproduced and reviewed within 72 hours. The recordings shall be preserved for a period of at least 30 days, in the possession of the station licensee, and must be made available to the Commission upon request. However, real-time monitoring, or recording and review of repeater operation is not required when the facility is operated as a closed repeater, i.e., the repeater station employs means to restrict usage to persons specifically authorized by the control operator or station licensee.

16-17 How are portable and mobile station licenses obtained?

An amateur station license authorizes the use under control of the licensee of all transmitting apparatus at the fixed location specified in the station license which is operated on any frequency, or frequencies allocated to the amateur service, and in addition authorizes the use, under control of the licensee, of portable and mobile transmitting apparatus operated at other locations. Therefore special licenses for portable and mobile operations are not required.

16-18 What are the responsibilities of a volunteer examiner?

The volunteer examiner shall be responsible for the proper conduct and necessary supervision of the examination. Administration of the examination shall be in accordance with the instructions included with the examination papers and as prescribed in the FCC rules and regulations.

The examination papers, either completed or unopened in the event the examination is not taken, shall be returned by the volunteer examiner to the Commission's office at Gettysburg, Pa., no later than 30 days after the date the papers are mailed by the Commission (the date of mailing is normally stamped by the Commission on the outside of the examination envelope).

16-19 The instrument of authorization for a radio station in the amateur radio service is:

- **A. The operator license.**
- **B. The transmitting apparatus.**
- **C. Part 97 of the Commission's rules and regulations.**
- **D. The station license.**
- **E. None of the above.**

Answer: *D*.

[illegible]

The [illegible] the Commission [illegible]

[illegible] The [illegible] to the amateur radio operator:

A. The operator license.
B. The transmitting apparatus.
C. Part 97 of the Commission's Rules and Regulations.
D. The station log.
E. None of the above.

Answer: C.

[illegible]

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MODERN AMATEUR RADIO LICENSE STUDY GUIDE FOR NOVICE, TECHNICIAN & GENERAL CLASS

BY WILLIAM A. HUNTER

Here is your "ticket" to the exciting world of amateur radio! It provides hundreds of detailed answers to the questions covered by all the FCC amateur radio examinations in every subject area. In addition to providing "over-the-shoulder" help for those taking any ham exam, it also provides a comprehensive general introduction to electronics.

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The author holds degrees in Electronic Engineering and Business Administration, and is active in ham radio (K6QAT); he lives in Orange, CA.

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